ECONOMIC CROPS

VOLUME III

COCOA

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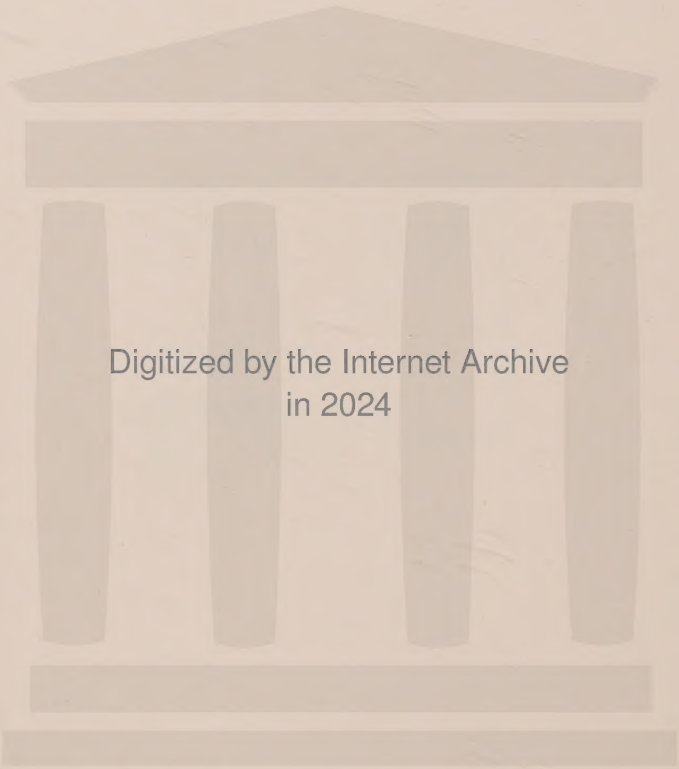

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COCOA

ECONOMIC CROPS

A series of monographs on the chemistry, physiology, and technology of food and food products

Z. I. KERTESZ, Editor

Volume I
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COCOA

CULTIVATION
PROCESSING
ANALYSIS

EILEEN M. CHATT
The British Food Manufacturing Industries Research Association, Leatherhead, Surrey

1953

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EDITOR'S INTRODUCTION

In the "Introduction to the Series" which appeared in the first volume of these monographs, emphasis was put on the many branches of science and technology which must play their part in the successful production and proper utilization of food crops. With increasing specialization, there is a tendency to devote intensified attention to certain specific aspects of our food production procedure, resulting in danger of losing sight of the over-all picture. The books in the *Economic Crops* series are designed to depict for the agriculturist the factors which will determine the suitability of the crop for storage, transport, and processing. Conversely, they are to give the technologist and manufacturer a better understanding of the botanical nature and biochemical behavior of food crops. Information on chemical composition and variability and on nutritive value are essential parts of these discussions. Thus, the aim is to give a complete view of the agricultural, biological, and technological factors and of the interrelation of factors which will determine the success of a crop to serve as human food, whether used in its original form or processed in some manner.

Unlike apples and bananas, the crops dealt with in the previous two volumes of this series, the cacao bean is a product which must pass through intricate technological processes to change its original form and nature completely before it will be ready for human consumption. Here indeed is a crop where utilization is impossible without the technologist. The producer of cacao beans and the technologist must be familiar with each other's problems if an acceptable final product is to be turned out in an economical manner. The need for such an over-all consideration is further underlined in the present case by the many serious problems encountered in cacao production, resulting in a rapidly changing production pattern.

Since the appearance of the first two volumes of this series, a development of great significance occurred. There is now a more intense exchange of information concerning agricultural and food pro-

duction methods than ever before. This trend, resulting from facing food production as a world-wide problem rather than that of a single nation, accentuates the need for technical information. It is also leading to a better appreciation of the fact that the problems of primary production are inseparably related to the technical problems of transport, storage, processing, and marketing. It is still too often that even large-scale agricultural production is started without fully considering the problems which will have to be faced once the crop is outside the farm gates, or that plans are made for the processing of food crops without having adequate regard for the many limitations in production. It is our sincere hope that these books will be of aid in some such instances.

Books in this series are written by specialists in addition to their daily tasks and therefore an exact timing of these monographs is difficult. The splendid reception accorded the first two books gave a further impetus to work on the series. It is hoped that with the appearance of *Cocoa* and the printing of the manuscripts now in preparation, the purposes and aims of this series will be partially fulfilled.

Z. I. KERTESZ

Colombo, Ceylon

PREFACE

In 1720, Linnaeus bestowed the name *Theobroma cacao* on the tree known in Mexico as *quacahault* or *caucauatl,* which for centuries had been extensively cultivated in Central America.

The choice of *Theobroma* (Greek for food of the gods) was a graceful compliment to the mythology of the Aztecs, who firmly believed in the divine origin of the seed. According to their tradition, it was a gift from the gods in Paradise, transported to them by Quetzalcoatl, the God of Air. So closely were the religion and husbandry of the Mexicans associated, that it was customary for the planting of the seed to be accompanied by impressive religious rites.

The word chocolate owes its derivation to *chocolatl,* the Mexican name for the beverage prepared from the seeds of *caucauatl,* which the colonising Spaniards called *cacao.* Corruptions of these two words, shortly found their way into the vocabularies of the Old World languages as exemplified in the following list:

Spanish	cacao	chocolate
Dutch	cacao	chocolaad
Italian	cacao	cioccolato
French	cacao	chocolat
German	Kakao	Schokolade
Portuguese	caucau	chocolate
Danish	Kakao	Chocolade

When the overseas trade was in its development stage, the raw material was used solely for the preparation of drinking chocolate. Cocoa powder is a comparatively modern commodity. Its arrival on the market, followed by the manufacture of eating chocolate, resulted in a tremendous expansion of the industry, which became known in English as the *cocoa* trade. How this particular corruption of the word cacao came about is not very clear, although in some of the earlier literature on the subject the cacao bean is occasionally referred to as the *coconut,* thereby adding to the general confusion. No distinction of spelling, as between the crop and its product, occurs in any other modern language.

Although no precise convention is followed in the literature in

English, there is a tendency to use the adjective cacao when writing about the crop and raw materials prepared from it and to restrict the use of the word cocoa for the description of finished products. While this practice has been adopted in the text, the choice of a title for this volume has proved difficult. For a monograph relating only to agriculture and primary processing, "Cacao" would have been more appropriate than "Cocoa" which has been selected because the following account embraces every stage in the commercial production of the familiar commodities associated with this very important crop.

Thanks are due to Mr. J. Nicol, Mr. R. V. Wadsworth, Dr. L. E. Campbell, Mr. L. R. Vyle, Messrs. J. and A. Churchill Ltd., Cadbury Brothers Ltd., Baker Perkins Ltd., Gebrüder Bühler, Savy Jeanjean et Cie, Walter Baker Division, General Foods Corporation and the Crown Agents for the Colonies for allowing illustrations to appear and to Miss F. J. Allen and Mr. P. R. Smith for their help in the preparation of some of them; to Mrs. L. Knapp, Professor F. Hardy, Dr. H. Fincke, Dr. K. Aasted and Mr. H. C. J. Wijnoogst for permission to reproduce tables from books; to Mr. E. C. Humphries whose researches are quoted at length in Chapter V; and to Dr. Z. I. Kertesz for his advice during discussions on presentation of the information collected in this volume.

E. M. C.

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AMERICAN AND BRITISH UNITS

oz. (ounce, Avoir.)	28.35 grams
lb. (pound, Avoir.)	0.4536 kilogram
cwt. (hundredweight)	112 lb.
ton (2240 lb.)	50.8 kilograms
	1.016 metric tons
gallon, Imperial	4.544 litres
in. (inch)	2.54 cm.
ft. (foot)	30.48 cm.
yard	0.9144 metre
acre	0.404 hectare
s.	shilling
d.	penny

CHAPTER I

HISTORY

1. Origin of the Cacao Tree

Fossil records are too scanty to provide any definite information as to the original home of the cacao tree. Other members of the same botanical order (Sterculiaceae), are better represented, most of the authentic ones, however, belong to old-world genera.

Unger[1] lists *Theobroma cacao* as occurring in the Post Pliocene of Antigua. Berry[2] described a calcified fruit from the Tertiary of Colombia as *Theobroma fossilium,* but according to Brown[3] this "fruit" is a section of the fore part of a reptilian jaw from the Cretaceous of Colombia. Berry[4] also recorded a specimen, *Theobroma tertiaria* Berry, from the Pliocene of Venezuela, which is part of a large leaf, comparable with that of recent *Theobroma cacao* Linn.

The belief that the forests of the Amazon and Orinoco were the original home of cacao is supported by the evidence that wild varieties of the tree flourish there in greater profusion than elsewhere. It is probable that its distribution over other districts of tropical America was achieved by nomad tribes. By all accounts, cacao cultivation by the Indians, notably the Aztecs of Mexico and the Mayas in Central America, was well established long before the New World was discovered. In 1502, during his fourth voyage, Christopher Columbus saw a cargo of cacao beans in a trading ship off the Gulf of Honduras[5] and the first specimens to reach Europe were those which he took back to Spain, as a souvenir of his voyage.

[1] F. Unger, *Synopsis Plantarum Fossilium.* Leipsig (1845).
[2] E. W. Berry, *Proc. U. S. Nat. Museum, 75,* 24, 1 (1939).
[3] R. W. Brown, *J. Washington Acad. Sci., 36,* 344 (1946).
[4] E. W. Berry, *Johns Hopkins Univ. Stud. Geol., 13,* 137 (1939).
[5] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.

2. Cultivation in Mexico by the Aztecs

The Aztecs had been settled in Mexico for nearly two hundred years when, in 1519, the Spaniard Cortes was conducting his campaign of conquest. Their civilisation was well advanced by the standards of that time. Of their agriculture, Prescott[6] writes: "It was closely interwoven with the civil and religious institutions of their nation. ... There was no want of judgement in the management of their ground. ... Its extreme dryness was relieved by canals with which their land was partially irrigated. Among the most important articles of their husbandry ... was the cacao, the fruit of which furnished chocolate—from the Mexican chocolatl."

The government was an elective monarchy, and the conquering Spaniards found the Mexican ruler, Montezuma, living in great pomp. His subjects paid a stipulated part of their produce as tribute to the Crown. Records were kept by means of picture-writing on cotton cloth, skins, or *maguey,* a fine fabric made from the leaves of aloe. Most of these were burnt by the Spaniards, who suspected that the hieroglyphics were connected with dealings in witchcraft, but amongst the few which survived is one known as the *Mendoza Codex,* which is preserved in the Bodleian Library in Oxford and consists largely of tribute rolls. Amongst items levied on different cities are:

20 chests of ground chocolate
800 xicaras (drinking vessels for chocolate)
80 loads of red chocolate
200 loads of chocolate

The Aztecs had no weights or scales and used measures or numbers to determine quantity.

When the Spaniards captured the palaces of Montezuma, they found enormous hoards of cacao beans. It was from these stocks that the beverage, *chocolatl,* was prepared for the emperor.

The treatment, prior to storage, was to dry the beans in the sun and roast them in earthen pots. After the husk had been removed, the "nibs" were placed on a flat or concave stone and ground by means of another stone, crudely shaped as a roller. The resulting fluid mass was mixed with corn and spices and made into cakes. To make the beverage, a piece of the cake was beaten up with water, by means of a

[6] W. H. Prescott, *The Conquest of Mexico.* Routledge, London, 1834.

whisk, known as a *molinet*. According to Prescott,[7] the preparation was almost solid enough to be eaten. He further states "The Emperor took no other beverage than the chocolatl, a potation of chocolate, flavoured with vanilla and other spices and so prepared as to be reduced to a froth of the consistency of honey which gradually dissolved in the mouth. This beverage, if so it could be called, was served in golden goblets, with spoons of the same metal or of tortoise shell finely wrought. The Emperor was exceedingly fond of it to judge from the quantity—no less than 50 jars or pitchers—prepared for his own daily consumption. Two thousand more were allowed for that of his household." The source of Prescott's information was the *Historia verdara de la Conquista de la Nuova-Espana,* written in 1568 by Bernal Diaz del Castillo, who accompanied Cortes. It was published in Madrid in 1632.

Chocolatl was consumed only by the wealthy, for the less privileged people had to be content to use cacao only as a flavouring in a food called atolle, prepared from corn meal.

At first the Spaniards were not greatly attracted by what must have been a very bitter decoction. Their "sweet tooth" had been developed by the use of the sugar cane, which was then unknown to the Mexicans, who relied on the stalks of maize for any sweetening matter they required.[8]

Besides being prized for their food value, cacao beans had another important use, for they were employed as a medium of exchange.

Robertson[9] gives the following account of barter at the time of the conquest of Mexico:

"The Mexicans, among whom the number and greatness of their cities gave rise to a more extended commerce than in any part of America, had begun to employ a common standard of value, which rendered smaller transactions much more easy. As chocolate was the favourite drink of persons in every rank of life, the nuts or almonds of cacao, of which it is composed, were of such universal consumption, that, in their stated markets, these were willingly received in return for commodities of small price."

A clue to their value is supplied by Thomas Cavendish (1586) who stated that 150 beans were equivalent to a Real of Plate, which

[7] W. H. Prescott, *The Conquest of Mexico.* Routledge, London, 1834.
[8] W. H. Prescott, *The Conquest of Mexico.* Routledge, London, 1834.
[9] W. Robertson, *History of America.* Vol. 3, Book 7, London, 1780.

was about sixpence in English money at that date. Human life must have been cheap, for the purchase price of a slave was 100 beans.

3. Importation of Cacao into Europe

Cortes, who was a practical man, realised that there were commercial possibilities in the development of the cacao crop. Between 1522 and 1524, the sugar cane was transplanted from the neighbouring islands and later, sugar mills were erected in Mexico.[10] The Spaniards found cacao more palatable when it was sweetened and they began to cultivate it in their other possessions, notably in Trinidad, in 1525.

In 1528, Cortes returned to Spain, taking with him samples of the prepared cakes and gradually the trade was established as the demand arose, but the method of preparation was kept as a closely guarded secret for many years.

Occasionally a cargo was captured from the Spaniards. A shipment was seized by Dutch corsairs, who found it so unpleasant that they threw it into the sea.

Despite the shroud of secrecy with which cacao was invested by the Spaniards, it became known to early explorers from other countries in Europe. It is mentioned in a manuscript, now in the British Museum, entitled *A Voyage to the West Indies and New Spain made by John Chilton in the year 1560.*

In 1565, Girolamo Benzoni published *The History of the New World* in Venice. He observed that cacao was grown in Nicaragua, Guatemala, Honduras and Mexico and an illustration is included, showing a cacao tree, protected by a shade tree, and some beans laid out nearby to dry in the sun. The inscription accompanying it reads as follows:

"Cacavate, which is money. The tree which produces it is not very large. It grows only in hot places, but under shade, for if the sun were to shine on it, it would die. Therefore they plant it in forests where it is humid, and, afraid that this is not enough, they plant it next to a tree which is higher and which they bend over it, spreading out its top so that it covers the cocoa tree, which thus gets shade all over it, so that the sun no longer does any harm."[11]

[10] W. H. Prescott, *The Conquest of Mexico.* Routledge, London, 1834.
[11] C. J. J. van Hall, *Cocoa.* Macmillan, London, 1914.

4. Popularity of Drinking Chocolate in Europe in the Seventeenth Century

In 1606, Antonio Carlotti, a Florentine, who had learnt to appreciate chocolate in Spain, introduced it into Italy and was also instrumental in introducing it into France in the reign of Louis XIII.[12]

When Louis XIV married Maria Theresa, who was very fond of chocolate, it became the fashionable drink at the court of France. The price was very high and therefore its use was limited to the aristocracy. In 1659, Chaillon David of Paris obtained the monopoly for the preparation of chocolate in France. The privilege was renewed in 1666 for 26 years and in 1692, the monopoly was transferred to Damame.[13]

The cultivation of cacao was commenced in Martinique by the French in 1660 and the first crop to reach the mother country arrived in 1679.[14]

In the seventeenth century, Venezuela became an important producer of cacao and shipment to Europe began in 1634.[15] The Spaniards failed in their attempt to acquire the entire crop and eventually the bulk of it found its way to Amsterdam, where chocolate was popular in 1660. The custom of chocolate-drinking had also spread to England and it became the vogue at Oxford in 1650.[16] A resort of the élite of London was the chocolate house in Queen's Head Alley, Bishopsgate Street, advertised in 1657. Soon others were opened and gradually they assumed the status of clubs, notable ones being White's Chocolate House and the Cocoa Tree, both of which were in the vicinity of St. James's Palace, London.

Turning to the drama for the manners of the times, it is significant that the opening scene of William Congreve's *The Way of the World,* produced in 1700, takes place in a chocolate house.

Judging from the fact that a duty of eightpence a gallon was imposed on chocolate in England in 1660, it seems probable that it was imported there ready made.[17] Further support for this view is found

[12] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[13] R. Whymper, *Cocoa and Chocolate.* Churchill, London, 1921.
[14] R. Whymper, *Cocoa and Chocolate.* Churchill, London, 1921.
[15] C. J. J. van Hall, *Cocoa.* Macmillan, London, 1914.
[16] A. Colmenero, *A Curious Treatise of the Nature and Quality of Chocolate.* English ed., 1685. (First published in Madrid, 1631.)
[17] A. W. Knapp, *Cocoa and Chocolate.* Pitman, London, 1923.

in a description by Hughes, in the *American Physician,* 1672.[18] "In Jamaica there is a sort of Chocolate made up of only the paste of Cacao itself, in rowls and lumps of a pound or two, the better for keeping good. And it may be had here in England, neat and good, of merchants and seamen that travel to these parts and bring it over."

Evidence that cacao was sold in Germany as early as 1640, is furnished by the price lists of apothecaries' shops,[19] for besides supplying the demands of the luxury trade in drinking chocolate, its stimulating power was fully realised.

Christopher Wilkinson[20] recommended variation of the ingredients of chocolate according to the constitutions of the consumers.

"In cold constitutions, Jamaica pepper, cinnamon, nutmegs, cloves etc., may be mixed with the cocoa-nut; some add musk and odiferous aromatick oils. In hot consumptive tempers, you may mix almonds, pistachios etc., sometimes china and arsa; and sometimes steel and rhubarb may be added for young green ladies." He also deplored the use of sugar as being "such a corrosive salt and such an hypocritical enemy of the body."

According to some opinions, the habit of drinking chocolate was regarded as dangerous. The following warning appeared in the *Spectator* (London), on the 29th of April 1712.

"I shall also advise my fair readers to be in a particular manner careful how they meddle with romances, chocolates, novels and the like inflamers, which I look upon as very dangerous to be made use of during this great carnival."[21]

In spite of its detractors, the demand for chocolate increased and in order to satisfy it, cacao from new sources found its way to Europe. In the seventeenth century, the Windward and Leeward Islands became important producers. When Jamaica was captured by the British in 1655, cultivation, started by the Spaniards, was already conducted on a large scale, and so it continued until the cacao trade of the West Indies received a great setback as the result of a "blast" in 1727, when the plantations in Jamaica, Trinidad and Martinique were wholly

[18] Hughes, *American Physician,* 1672; Historicus, *Cocoa: All About it.* Sampson Low, London, 1896.
[19] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[20] Christopher Wilkinson, *The Natural History of Chocolate,* London, 17th cent.; Historicus, *Cocoa: All About It.* Sampson Low, London, 1896.
[21] *Spectator,* London, 29th April 1712; Historicus, *Cocoa: All About It.* Sampson Low, London, 1896.

destroyed. It took at least thirty years to re-establish them in Trinidad, but in Jamaica, cacao cultivation was almost abandoned for about a hundred and fifty years.[22]

5. Eighteenth Century Improvements in Methods of Grinding

During the seventeenth century, grinding was still accomplished solely by manual labour. This was superseded by water-power, the

Fig. 1. The Chocolate Server. (Jean Etienne Liotard, 1702–1789, by courtesy of Walter Baker Cocoa and Chocolate Division, General Foods Corporation.)

pioneers being Dr. Joseph Fry of Bristol, England, who founded the firm of Fry & Sons in 1728 and Dr. James Baker of Dorchester, Mass., U.S.A., founder in 1765 of the firm known as Walter Baker & Co., since 1852. About 80 years ago, this firm acquired the replica of the Dresden Art Gallery portrait of a chocolate server[23] (Fig. 1), painted

[22] C. J. J. van Hall, *Cocoa*. Macmillan, London, 1914.

[23] *Private communication* to the author from Walter Baker Chocolate and Cocoa Division, General Foods Corporation, Dorchester, Mass.

circa 1745 by the Swiss artist Jean Etienne Liotard, for use as their trademark.

That the cacao industry had already assumed some importance in the United States is shown by the fact that in 1783 it was proposed to raise revenue by an impost on liquor, sugar, tea, coffee, cocoa, molasses, and pepper.[24]

In France chocolate enjoyed a good reputation for flavour and the preparation was still carried out by hand work although, in 1770, Doret had invented steam-driven machinery for the manufacture of chocolate, but it did not find practical application in any of the factories there. It was in 1795 in England that Messrs. Fry & Sons made history in their Bristol factory, by being the first firm to instal a steam engine for grinding chocolate.

Stimulus was thus given to the trade, which was, however, still hampered by heavy duties in many countries. The total amount of cacao imported into Great Britain at the close of the eighteenth century did not exceed one hundred tons per annum.[25]

6. Introduction of the Cacao Tree into Asia

Despite the heavy import duties and taxes, which made illicit trade a profitable business, the demand for cacao continued to increase. As already noted above, the plantations in the West Indies suffered almost total destruction at the beginning of the eighteenth century, but to set against this, new sources of supply were gradually springing up in Asia.

The Spaniards are said to have introduced the cacao plant into Celebes as early as 1560, but its cultivation there was never very important. In 1860, it was introduced into the Philippine Islands. The plantations of the Dutch colonists in Java and Sumatra and of the Portuguese in Timor are of a much later date.

The Dutch were also the first planters of cacao in Ceylon, after the failure of the coffee crop there, but the parent plants of the present crop were obtained from Trinidad by Sir R. Horton in 1834.

[24] J. B. McMaster, *A History of the People of the United States from the Revolution to the Civil War*, Vol. 1, 1784–1790. Appleton & Co., New York and London, 1924. Quoting *Journals of Congress*, 18th April 1783.
[25] A. W. Knapp, *Cocoa and Chocolate*. Pitman, London, 1923.

7. Expansion of the Industry Owing to the Manufacture of Eating Chocolate and Milk Chocolate

At the close of the eighteenth century, there were chocolate factories in all the principal cities of Germany. The beginning of the nineteenth century saw the birth of many firms which are still famous in Europe. In 1804, the firm of David was founded at Halle and in 1817 the firm of Hildebrand, Berlin, was established. In 1839, the firm of Stollwerck, prior to the Second World War the largest chocolate undertaking in Germany, was founded in Cologne. In 1815, the firm of van Houten and Zoon was established in Holland. In 1819, the firm of Cailler was founded at Vevey in Switzerland and the Menier factory in France dates from 1825. A year later, the Swiss firm of

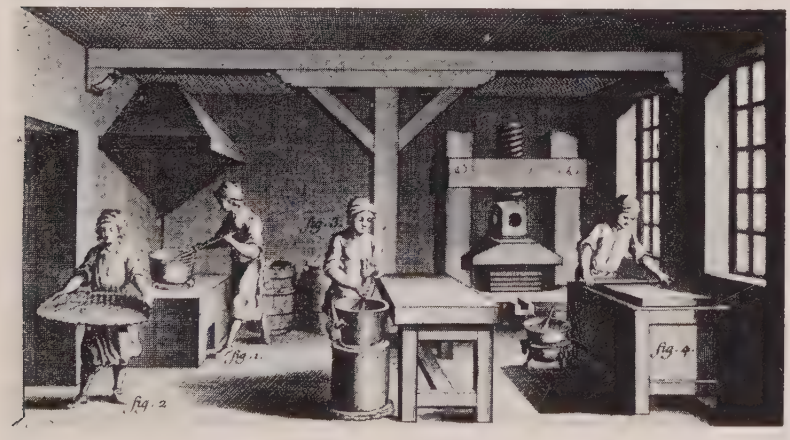


Fig. 2. Interior of a French chocolate factory in 1763, showing a cocoa butter press in the background. From the *Encyclopaedia of Diderot and d'Alembert*, 1767. (By courtesy of the Director, British Food Manufacturing Industries Research Association.)

Suchard commenced production and the Kohler factory in Lausanne arose in 1830. At Birmingham, England, in 1831 the firm of Cadbury was founded, while at York, the firm of Tuke, later to become Rowntree & Co., Limited, had been manufacturing chocolate since 1785.

The produce of these factories consisted of drinking chocolate, a rich and somewhat indigestible beverage, for it was not customary to remove any of the fat, but to dilute the cacao with starchy matter, as the Aztecs had done. The farinaceous material commonly used was

maize, but later it became the custom to use arrowroot. To this day, the British Navy drinks this kind of chocolate.

As early as 1763, in the *Encyclopaedia of Diderot and d'Alembert,* an illustration of a French chocolate factory appeared, in which a press is shown for defatting cacao (Fig. 2). At about the same time, Merli[26] observed that partially defatted cacao produced the best chocolate.

In 1828, the Dutch firm of van Houten took out a patent for the manufacture of "chocolate powder," consisting of cacao from which about two-thirds of the fat had been expressed. Thus, for the first time, the now familiar article, cocoa, was manufactured.

A new use was soon found for the by-product, cocoa butter, when it was discovered that by mixing it with cacao and finely ground sugar, a delectable article was prepared which was capable of being moulded into bars. The manufacture of this "eating chocolate" commenced only about a century ago. It was sold by Messrs. Fry & Sons in 1847 and Cadbury Bros. displayed samples of it at an exhibition in 1849.[27]

As a consequence of the reduction of heavy duties on cacao entering Great Britain, it was possible to produce cocoa and chocolate at prices within the purchasing power of a wider public, and the demand rose steadily. Unfortunately, adulteration became very usual. The extent of it may be gauged by a report of the Analytical Sanitary Commission of 1851, on sixty-eight samples of cocoa. Of these, only eight were free from adulteration.[28] The commonest forms of sophistication were the addition of potato starch and mineral pigments.

Tresper Clarke[28a] has drawn attention to the description of an alkali treatment for improving the digestibility of cacao, published in Mexico by Osasunasco in 1789.

Over a long period of years, it was a debatable point among manufacturers, as to whether the addition of alkali should be hailed as a progressive step or regarded as a departure to be discouraged. The practice of adding a small amount of carbonate or bicarbonate during the manufacture of cocoa powder is now almost universal. C. J. van Houten was the pioneer of a process for the manufacture of

[26] F. Merli, *Guida medico intorno all' uso del Thé, Caffé e Cioccolata.* Naples, 1768.

[27] A. W. Knapp, *Cocoa and Chocolate.* Pitman, London, 1923.

[28] Historicus, *Cocoa: All About It.* Sampson Low, London, 1896.

[28a] W. Tresper Clarke, in lecture to American Association of Candy Technology, Philadelphia, Jan. 1953.

"soluble cocoa," so-called because the added alkali causes the particles to remain in suspension for some time after the drink has been prepared. Alkali darkens and enriches the colour of the product. Opinions differ as to whether the flavour is also improved. Half a century ago, alkalisation was condemned by Richard Cadbury, who, writing under the pseudonym of "Historicus" asserted—"The true reason for the addition of alkali is apparent to the initiated. It gives a deceptive value to the cocoa by darkening its colour in the cup."[29] In some of the cocoas to be met with at that time, it is more than likely that the alkali had not been added with discretion.

In Switzerland, where the manufacture of chocolate had become an industry of first-rate importance, a new development occurred in 1876, owing to the invention of milk chocolate by M. D. Peter. An additional stimulus to the trade was provided by the quick rise to popularity of this novelty. Other new uses for chocolate were as a coating for fondants and biscuits and also for flavouring cakes and puddings.

8. Introduction of the Cacao Tree into Africa

To meet the continually increasing demand, raw material became available from newer sources and although there was a falling off in exports from some of the older cacao-producing countries, others showed a considerable expansion in their trade.

According to the Gordian Treatise,[30] the estimate of average annual world exports from 1830 to 1890 was:

14,000 tons in the decade 1830/1840.
16,000 tons in the decade 1840/1850.
19,000 tons in the decade 1850/1860.
23,000 tons in the decade 1860/1870.
31,000 tons in the decade 1870/1880.
41,000 tons in the decade 1880/1890.

Within the next decade, cacao exports from Africa began to be important, especially from San Thomé and Principe.

The Spaniards planted cacao in Fernando Po in the seventeenth century, but the industry only became important towards the end of

[29] Historicus, *Cocoa: All About It.* Sampson Low, London, 1896.
[30] Anon., *Gordian Essays on Cocoa.* Max Rieck, Hamburg, 1936. (World Exports of Cocoa Beans).

the nineteenth century. In 1800, the French planted trees in Madagascar, but exports from there were only on the small scale. At the end of the nineteenth century, the trade was being built up in the Cameroons by the Germans and by the Belgians in Belgian Congo.

In 1879, the first cacao was planted in the Gold Coast, where it was introduced from Fernando Po, an island off Nigeria in the Gulf of Guinea. In 1891, a modest eighty pounds of beans was exported and by 1894, the amount had risen to 9 tons, as against 18 tons exported from Nigeria. By 1904, the export from the Gold Coast was 5773 tons, ten times the output from Nigeria. Since then, the output has rocketed up to an amazing extent and by 1935, one-third of the total world production of cacao was raised in the Gold Coast, largely by native farmers, who are assisted by advice from the Department of Agriculture. Recent years have shown a decrease in yield, due to the ravages of swollen shoot disease.

The measures which are being taken to combat this serious menace are dealt with in Chapter IV,1B.

9. Recent Developments in the Cacao Industry

The more recent history of the cacao industry is inseparably bound up with research from the agricultural standpoint as well as on the manufacturing side of production. Diseases are taking their toll of the crops and agricultural organisations are striving to repair the ravages by encouraging the development of resistant varieties. New sites must be found to replace those where the soil has become impoverished or too little attention has been paid to reafforestation.

In order to lessen production costs, time-saving machinery has been evolved with the aim of improving efficiency. Methods of storage may enhance or mar the product. Economy of fat has been achieved by the addition of lecithin, which is also said to lengthen shelf life. The ultimate goal of all these efforts is the production of palatable articles at a reasonable price. The improved standard of production is in some measure due to laboratory personnel, whether they be engaged in the detection of sophistication or in solving the problems of the manufacturer.

The history of the cocoa industry would be incomplete without reference to some of the organisations engaged in research.

On the agricultural side of the industry, notable contributions

are being made from the Imperial College of Tropical Agriculture in Trinidad and the West African Cacao Research Institute at Tafo, Gold Coast. At the end of the Second World War, the American Cocoa Research Institute was formed. Its efforts are concerned with the improvement of agricultural methods, with a view to increasing the output in Latin-Amtrican countries.

Shortly after the First World War, a government-aided research laboratory was opened in London, to deal with problems connected with the manufacturing side of the industry. Formerly known as the British Association of Research for the Cocoa, Chocolate, Sugar Confectionery, and Jam Trades, its scope has now been widened by amalgamation with the British Food Manufacturers Research Association and the new title of the organisation is the British Food Manufacturing Industries Research Association.

The activities of the Office International du Cacao et du Chocolat, with headquarters in Brussels, in abeyance during the recent war, have now been renewed. The organisation provides an information service and aims at the unification of analytical methods.

Chocolate has ceased to be regarded as a mere luxury and is now recognised as a valuable article of diet.

During both world wars, chocolate tablets proved their worth as handy emergency rations for troops. Shortage of cacao and milk led to new developments, created largely through the outcome of necessity. In Germany, in particular, de-bittered soya flour was introduced as an ingredient of chocolate.[31] It was claimed that the keeping qualities were improved, by reason of the antioxidant properties of soya. Cocoa was prepared without milk by mixing 80% of cocoa powder with 20% of soya flour. The German cocoa press cake contained only 10% of fat or even less, owing to the serious shortage of fats.

Faced with dwindling stocks of cacao, the German High Command issued a chocolate containing kola to eke out supplies.[32] The preparation was said to possess superior keeping qualities and proved its worth during the North African campaign.

With a view to arresting malnutrition, the allied governments prepared rations of relief chocolate, containing added vitamins and

[31] W. Straub and C. Mangan, *British Intelligence Objectives Sub-committee Miscellaneous Reports No. 17.* His Majesty's Stationery Office, London, 1946.
[32] W. Straub and C. Mangan, *British Intelligence Objectives Sub-committee Miscellaneous Reports No. 15.* His Majesty's Stationery Office, London, 1946.

calcium, for distribution in liberated countries. The energy value of the familiar chocolate tablet is high and the presence of theobromine and caffeine endow it with mild therapeutic qualities. Through lack of accessory factors, it falls short of being a perfect food. It is, however, a satisfactory base for the incorporation of supplementary vitamins.

The demand for cacao is ever increasing and the supply position is becoming more critical as the number of disease-infected trees continues to mount at an alarming rate. As rehabilitation of older areas and production in new territories are proceeding but slowly, owing to shortages of labour and planting material, there will probably be a world shortage of cacao for some years to come.

CHAPTER II

BOTANY

1. Classification

All the members of the genus *Theobroma* are woody plants, some of which are shrubs and others relatively small trees. They are assigned to the sub-group Buettneriaceae of the order Sterculiaceae, a family closely related to the Malvaceae. The only members of Sterculiaceae which are extensively cultivated to supply food for human consumption are the kolas and those varieties of *Theobroma* whose seeds, known as cacao beans, are used as a basic ingredient of cocoa and chocolate.

At least twenty species of *Theobroma,* embracing both wild and cultivated types, have been described. Commercially, *T. cacao,* Linn. is by far the most important. The original types of cacao are unknown. Among cultivated types, *T. pentagona,* Bern., *T. leiocarpa,* Bern., and *T. sphaerocarpa,* Chev. were formerly accepted as distinct species. Kaden[1] maintains that they are mutations of *T. cacao,* Linn. and this view has the support of many modern botanists. On the other hand Holdridge[2] believes that *T. pentagona* and *T. leiocarpa* are valid species, and uses the notation *T. leiocarpa* x *T. pentagona* to represent the cultivated cacaos of Central America and Mexico. It is probable that *T. pentagona* was the only kind of cacao in cultivation when the Spaniards invaded Mexico.

From the commercial standpoint, two fundamental groups of cultivated cacao are recognized. These are Criollo, bearing warty fruits containing white or faintly purple seeds and Forastero, bearing smoother fruits containing seeds of a deeper purple shade. Between these two groups are a number of hybrids containing both Criollo

[1] O. F. Kaden, *Gordian Essays on Cocoa.* Max Rieck, Hamburg, 1936.
[2] L. R. Holdridge, *Cacao Information Bull., 2,* No. 1, 1 (1950).

and Forastero genes. Their number has been increased during recent years through exchanges effected between cacao producing countries.

Criollo means "native" and Forastero "foreign." The contra-distinction arose in Venezuela after the introduction of cacao trees from the West Indies, when the terms were used to denote the local and imported kinds of cacao.

Hart[3] classified cacao in three groups, Criollo, Forastero, and Calabacillo, the last-named being distinguished from the others by its shorter, smooth pods and flat, dark purple seeds. Calabacillo cacao is not now regarded as being sufficiently distinct in its characteristics to be referred to a separate group. Its accepted position in the scheme of classification is as the lowest grade of the Forastero group. The sub-divisions of Forastero cacao are based on the shapes of the fruits. Cheesman[4] points out that such distinctions are insufficient to merit the status of varieties. He asserts that the classification

1. Criollo
2. Forastero
   a. Angoleta
   b. Cundeamor
   c. Amelonado
   d. Calabacillo

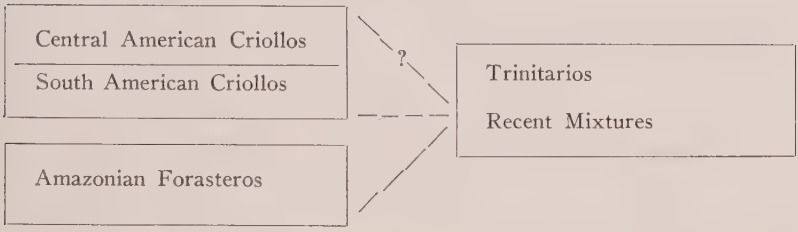
(in which the sub-divisions a to d apply to the shape of fruits and Angoleta is closest in character to Criollo) is unsatisfactory in that the Forastero group is made to cover all non-Criollo types. He therefore proposes the reorganisation of the groups in the following manner:

1. Criollo { Central American Criollos / South American Criollos }
2. Forastero
   a. Amazonian Forasteros
   b. Trinitarios

Thus the distinction between Criollo and Forastero is preserved, while provision is made for separating hybrid populations. Trinitarios are hybrids of South American Criollos and Amazonian Forasteros. Distinction is made between the Trinitarios of Trinidad and those cultivated in West Africa. Trinitarios are unknown in the wild state. Cheesman states that *T. pentagona*, Bern. and *T. leiocarpa*,

[3] J. H. Hart, *Cacao*. Duckworth, London, 1911.
[4] E. E. Cheesman, *Trop. Agr. (Trinidad)*, *21*, 144 (1944).

Bern. are forms of Central American Criollos without merit of special status and may therefore be referred to *T. cacao,* Linn., and illustrates the probable relationship between the groups thus:



On all types of cultivated *Theobroma* plants, the flowers appear only on the trunk and main branches. *T. bicolor,* one of the most widely distributed non-cultivated species, is distinguished by the presence of flowers in the axils of young leaves on the smaller branches. Zipperer[5] states that its seeds are sometimes to be found mixed with cacao beans from the Caracas district of Venezuela. Its cultivation is not considered economic, because it does not bear fruit until the eighth year and the pulp is developed at the expense of the seeds. It is better able to withstand drought than *T. cacao.* For this reason, Hart[6] suggested that it might profitably be used as stock for grafting.

Trials are in progress at the West African Cacao Research Institute to determine the degree of resistance to disease of uncultivated species of *Theobroma.* Although it is early to make recommendations, *T. herrania* promises well and it may therefore have a future as a commercial type.[7] It comes into bearing after only two years, yields well and its seeds are considerably richer in fat than those of *T. cacao,* but its fruits are very much smaller. Trials for quality of flavour are in progress.

Commercially, Criollo and some Trinitario types of cacao are classified as "choice" from the quality of their flavour, and the lower Forastero types as "ordinary" for bulk. In 1913, 42% of the world crop consisted of choice cacao. By 1939, the output of choice cacao

[5] F. Zipperer, *Die Schokoladen-Fabrikation.* 3rd ed., Krayn, Berlin, 1913.
[6] J. H. Hart, *Cacao.* Duckworth, London, 1911.
[7] A. F. Posnette, *18th Quarterly Report. West African Cacao Research Institute.* Oct.–Dec., 1948.

had declined to 10%.[8] This downward trend is due to the replacement of diseased trees by more vigorous but inferior types and to the rise in output in West Africa, where the crop consists of bulk cacao. Flavour grades of cacao are grown in Ecuador, Venezuela, Central America, the West Indies, Ceylon and Samoa and bulk grades in West Africa and Brazil.

2. The Cacao Tree

A. GENERAL MORPHOLOGY

The cacao tree attains its full height when about ten years old. According to variety and local conditions, a fully grown tree is be-

Fig. 3. Mature Forastero cacao trees, West Africa. (By courtesy of Cadbury Brothers Ltd.)

[8] E. G. Montgomery and A. M. Taylor, *World Trade in Cocoa*. U. S. Government Printing Office, Washington, 1947.

tween 15 and 25 feet high. The main branching system is then from three to five feet above the ground and the foliage may measure from 20 to 26 feet across, when free development is allowed.[9] The wood is light coloured and the thin bark is grey.

The morphology of the root system varies according to the texture of the soil. The thickness of the main rooting zone in a good soil may be from 12 to 20 inches.[10] When the soil is light, the tree has a tap root several feet long. In heavy clay soils, the tap root is shorter and lateral roots are extensive. Mulloon[11] describes such a cacao root system thus:

> Tap roots 27 inches long for trees and 41 inches for chupons, laterals mainly 18–20 inches in depth. Branch roots are most profuse in the upper 16 inches of soil and fine roots and fibrous rootlets associated with humus are situated in a shallow surface layer. The mean horizontal spread of laterals is 16 feet and some meander for 20 feet. Not all trees possess anchor roots.

The main stem of a young cacao plant may grow to three or five feet in height before branching. Leaves on the main stem and chupons (suckers) are arranged spirally according to a system represented by the notation 3/8 which indicates that the ninth leaf arises directly above the first leaf and the intermediate leaves are so distributed that if a line were drawn to pass through their axils, three coils of a spiral would be traced between the first leaf and the ninth one. Leaves on branches are alternate. Cacao puts forth new shoots several times in a year. Each shoot ends in a terminal bud enclosed in scales. When the bud bursts into leaf (leaf flush) and a new shoot is developed, the scales are shed, leaving scars which form a ring scar between each successive shoot.[12]

Young cacao leaves vary in colour, according to type, from pale green or pink to dark red. They are protected by a pair of stipules at the base of the stalk. The stipules are shed as the leaves mature. Mature leaves are evergreen and sometimes attain a length of 15 inches and a breadth of 3 inches. The short stalk is provided with two articulations for guiding the upper surface of the leaf towards

[9] C. J. J. van Hall, *Cocoa.* Macmillan, London, 1914.
[10] C. W. R. McCreary, J. A. MacDonald, V. I. Mulloon and F. Hardy, *Trop. Agr. (Trinidad), 20,* 207 (1943).
[11] C. W. R. McCreary, J. A. MacDonald, V. I. Mulloon and F. Hardy, *Trop. Agr. (Trinidad), 20,* 207 (1943).
[12] C. J. J. van Hall, *Cocoa.* Macmillan, London, 1914.

the light. The upper surface is glossy. The leaf edge is entire and the tip is pointed (Fig. 4).

Flowers are seen on the cacao tree at all times of the year, growing in clusters, either on the trunk or main branches. Bywaters states that as many as 6000 may be produced on a tree in one year.[13] They are small, white or pale pink in colour and have no scent. Only about 1% of the flowers come to fruition.

Fig. 4. Cacao leaf.

The fruits (pods) are about 6 to 8 inches long when ripe and are then yellow, red, or maroon in colour, according to the variety. They weigh about a pound and contain 25 to 40 seeds.

Trinitarios begin to bear in the third or fourth year and reach their maximum in the eighth year. Criollos produce a few fruits in the fifth or sixth year, but the yield is not appreciable until the seventh or eighth year. They come into full bearing by the tenth year.

The life of a tree depends on the quality of the soil and to what extent its upkeep has been maintained. Some trees continue bearing for 50 years, but under ordinary conditions of culture, the yield decreases after 25 years and may cease to be economic during the next 20 years. In reference to trees said to be 100 years old, Briton-Jones[14] points out that the original trees have been replaced by chupons.

The average tree yields 20 to 30 fruits (pods) per year. Each pod produces about 1.5 ozs. of fermented and dried cacao of commerce.

B. FUNCTIONS OF THE LEAF

It is well known that the leaf is the site of elaboration of sugars from atmospheric carbon dioxide absorbed through the stomata and

[13] H. W. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture*. Churchill, London, 1930.

[14] H. R. Briton-Jones, *The Diseases and Curing of Cacao*. Macmillan, London, 1934.

that this process, known as photosynthesis, is brought about by the action of chlorophyll present in the chloroplasts, under the influence of light. By a series of transformations, polysaccharides, acids, fats and proteins are synthesized from the primary products of photosynthesis and substances conveyed from the roots by transpiration. The exact mechanism is not clearly understood. The degree of photosynthetic activity depends on the concentration of stomata on the leaf surface. Cacao trees are usually grown under the shade of other trees (see Chapter III, p. 32). Cabrera[15] studied the effect of varying degrees of shade on concentration of stomata. Leaves were selected from the top, centre, and bottom of the foliage of trees grown under 90%, 50%, 25%, and no shade. Four counts were made from each leaf, over an area of 0.96 sq. mm. No significant difference in the number of stomata was found for leaves grown under 90% and 50% shade. Lower counts were recorded for 25% shade and the number was still less for leaves from trees grown without shade. The stomata were observed to be progressively larger with decreasing shade. The greatest stomatal area was observed for 50% shade, which therefore appears to be the most desirable condition for cacao cultivation.

Humphries and McKee[16] studied the carbohydrate changes during leaf flushes of cacao trees. Flushes (bud-bursting) occur four or five times a year in Trinidad.

When the temperature is favourable (83°F.–84°F.) leaf flushes occur at intervals of seven weeks, thus allowing the new bud just sufficient time to reach maturity and build up its food reserves. It is possible that the cacao leaf may be efficient for a longer time than the period between two flushes. Normal flushing rarely occurs at temperatures below 83°F. (28.3°C.). When the interval between flushes is eight weeks or less, the successive ones are weaker because the carbohydrate reserves are limited.

During the development of a flush, total reducing sugars, sucrose and starch in older leaves showed little variation, the fluctuations of sucrose being rather more marked than those of reducing sugars and starch. Starch showed a slight upward trend at first and decreased during the fifth and ninth weeks. In older stems, the starch reserves utilised at the outset of the new flush require eleven to twelve weeks for replacement. Values fluctuated more in young leaves

[15] L. Cabrera, *Cacao Information Bull., 1,* No. 22, 6 (1949).
[16] E. C. Humphries and R. K. McKee, *Ann. Rept. Cacao Research, Imp. Coll. Trop. Agr. (Trinidad).* No. 11 (1941–43), pub. 1944.

than in older leaves. In young stems, sucrose declined at first and then rose gradually to surpass its original value after fourteen weeks. Sucrose fluctuations may bear some relationship to maximum air temperatures.

Humphries[17] determined the relationship between leaf expansion and growth of the whole tree by measuring the diameters of stems twice daily over a period of eighteen months. Increases in diameter during leaf flush are due to cambial activity and it is probable that a ring is laid down. Increases during rains cause bark swellings which are not permanent.

The initial stem diameter was 11 cm. During the first flush, there was a continual increase of diameter for eight days, after which the readings remained high and then, when the leaves hardened, fell to approximately the same as before the flush. The overall increase after five months was 0.04 mm. In the second flush, there was a more marked increase, despite a very dry season, and, after a fall when extension growth was ceasing, the permanent diametral increase was 0.06 mm. The third flush, during the wet season, was more prolonged because bud bursting was gradual and the net increase was 0.1 mm.

C. THE FLOWER

Flower buds are hidden in the axils of leaves. The leaf may have fallen by the time the flowers are in blossom. The inflorescence is cymose, in the form of a dichasium, a system in which the main axis bifurcates into two lateral shoots and each succeeding axis bifurcates. In cacao, the main axis and secondaries are merely vestigial and the flowers appear to be grouped in a tiny cluster. The calyx consists of five pink or white pointed sepals. The five petals forming the corolla are broad at the base, then narrow to a strip curling back over the base and terminate in a spatulate appendage. They are either white or pink, with two red ridges on the inner surface of the basal end. Five short stamens, each surmounted by four anthers, alternate with five long, red, pointed staminodes.

The stamen filaments of all West African Amelonado, Trinitario and Criollo types inspected by Posnette[17a] are either unpigmented or faintly tinged with purple, and all Ecuador types inspected have pigmented filaments varying in colour from pink to maroon. This chacteristic is also present in some Amazonian populations. It is not associated

[17] E. C. Humphries, *Ann. Rept. Cacao Research, Imp. Coll. Trop. Agr. (Trinidad)*. No. 11 (1941–43), pub. 1944.
[17a] A. F. Posnette, *Trop. Agr. (Trinidad), 22,* 184 (1945).

with the pigment on leaves or pods. The ovary is superior and is surmounted by a slim style, bearing five small stigmata (Fig. 5).

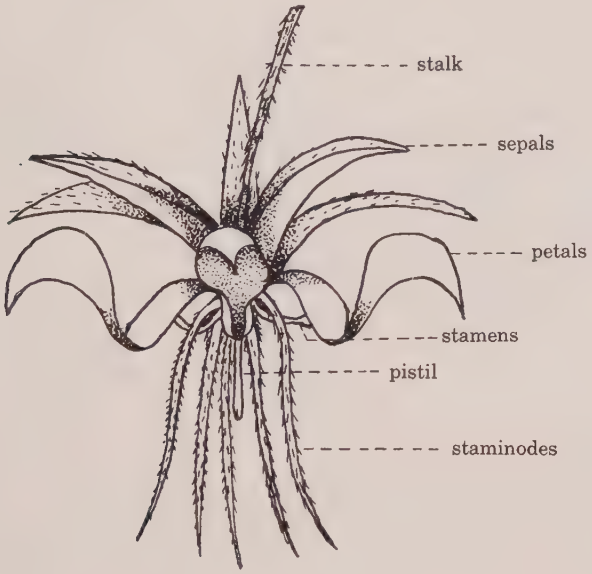


Fig. 5. Cacao flower, ×6. (Original drawing by J. Nicol.)

D. POLLINATION

Self-compatible (homozygous) types are fertilized by pollen from their own flowers. Self-incompatible (heterozygous) types can only be fertilized by the pollen of flowers from other trees.

All cacao trees are interfertile and show a high rate of cross-pollination in the field.[18] Pollination experiments undertaken by Voelcker[19] revealed that self-incompatibles when crossed with other self-incompatibles set rarely or not at all. Out of 245 flowers pollinated by hand, only one fruit had set after 14 days. When 228 self-incompatibles were crossed with self-compatibles, 190 fruits had set after 14 days. Out of 87 self-compatibles crossed with self-incompatibles, 70 fruits had set in 14 days.

[18] E. E. Cheesman, *Trop. Agr. (Trinidad), 21,* 144 (1944).
[19] O. J. Voelcker, *Ann. Rept. Cacao Research, Imp. Coll. Trop. Agr. (Trinidad).* No. 7 (1937), pub. 1938.

Posnette[20] reported a case of self-incompatibility in the Amazonian type, West African Amelonado. Whereas this is an unusual feature of Amelonado, self-incompatibility is regarded as characteristic of fine types of the genus *Theobroma*. Upper Amazon and Ecuador types introduced into Trinidad have been shown by hand-pollination to be self-incompatible. They differ from incompatible Trinitario types in being cross-compatible.

Self-compatible types excel in the number of fruits set, but lose a greater proportion through physiological wilt than self-sterile types. Nevertheless, self-compatible trees bear a greater number of harvestable fruits.[21]

The insect species concerned with cross-pollination of cacao remained a subject of much speculation until recently. Formerly, thrips were believed to be responsible for the pollination of cacao flowers. This may be true in occasional instances, but it has now been established that the Ceratopogonid midge, *Forcipomyia* is the chief insect concerned.[22]

Insects identified as being responsible for cross-pollination in West Africa are *Forcipomyia ingrami*, Carter, *Forcipomyia ashantii*, Ingram and Macfie and *Lasiohelia litoraurea*, Ingram and Macfie. In Trinidad, *Forcipomyia quasi-ingrami* and *Lasiohelia nana*, Macfie appear to be the chief cross-pollinating insects.[23] The rate of pollination increases between the time of the opening of the flower until noon.

E. DESCRIPTION OF CACAO FRUITS

The flower stalk is composed of a basal part bearing scales and a true stalk. When the fruit is developing, the true stalk becomes woody and the scales fall off, leaving scars. When the fruit is harvested, the basal part is allowed to remain on the tree to form a cushion, and the next season's flowers arise from the axils of the scales.

The mature fruit (Fig. 6) is composed of a fairly thick husk containing a number of seeds which are invested by a mucilaginous pulp. The seeds are held in position by the placenta. The finer varieties

[20] A. F. Posnette, *Trop. Agr. (Trinidad), 22*, 184 (1945).
[21] F. W. Cope, *Ann. Rept. Cacao Research, Imp. Coll. Trop. Agr. (Trinidad)*. No. 9 (1939), pub. 1940.
[22] D. J. Billes, *Trop. Agr. (Trinidad), 17*, 8, 151 (1941).
[23] O. J. Voelcker, *Ann. Rept. W. African Cacao Research Institute* (1945–46), pub. 1947.

of cacao are characterized by having warty pods and light-coloured seeds. Quality deteriorates as the pods become smoother and the seeds more deeply pigmented.

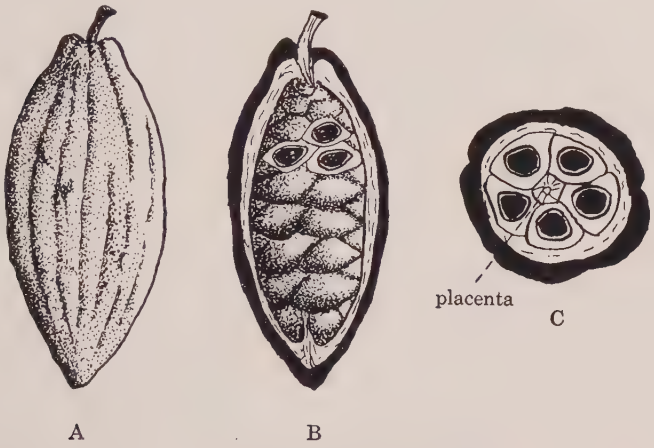


Fig. 6. Cacao fruit, $\times^1/_8$. (A) Forastero-amelonado pod. (B) Interior of pod, showing pulpy inner layer and mucus surrounding the beans; three of the beans have been cut open. (C) Cross section of pod, showing beans and placenta. (Original drawing by J. Nicol.)

Detailed descriptions of different types of fruits are given by Zipperer,[24] Hart,[25] van Hall[26] and Kaden.[27]

(1) SOUTH AMERICAN CRIOLLOS

The red or yellow, long and slender pods broaden towards the stalk and taper to a distinct point at the tip. The warty fruit wall is soft and has five deep furrows alternating with five less pronounced ones. The seeds, which are plump, may be white or pale purple.

(2) CENTRAL AMERICAN CRIOLLOS

The pods, though somewhat similar to those of South American Criollos, exhibit a tendency to asymmetry which is very pronounced

[24] F. Zipperer, *Die Schokoladen-Fabrikation.* 3rd ed., Krayn, Berlin, 1913.
[25] J. H. Hart, *Cacao.* Duckworth, London, 1911.
[26] C. J. J. van Hall, *Cocoa.* Macmillan, London, 1914.
[27] O. F. Kaden, *Gordian Essays on Cocoa.* Max Rieck, Hamburg, 1936.

in *T. pentagona,* known as the "alligator" cacao of Mexico on account of the scaly appearance of its surface. Five well-marked ridges are present. The seeds of Central American Criollos are generally large. This is especially the case in Nicaragua Criollo.

(3) FORASTEROS AND TRINITARIOS

According to the appearance of the pods, this group can conveniently be subdivided under Angoleta, Cundeamor, Amelonado and Calabacillo.[28]

Forastero and Trinitario pods are either yellow or red. Referring to the origin of Trinitario cacao, Posnette[29] states that it may have come from the Orinoco or Colombia as an already variable type, or have been synthesized in Trinidad by hybridisation between a Central American Criollo and an Eastern Amazon type.

Angoleta (also known as Liso) has large fruits with a thick, deeply furrowed warty wall and closely approaches Criollo in its characteristics. The seeds are rounded, plump and pale purple.

In Cundeamor fruits, the furrows are less pronounced and the surface less warty than in Angoleta. The seeds are fairly pale purple, but tend to be slightly deeper in tone than those of Angoleta.

Amelonado, an Amazonian Forastero, is the most commonly cultivated kind of cacao. The smooth pods are either rounded or slightly pointed at the tip and have ten very distinct furrows. The seeds are fairly plump and are usually purple, although white seeds do sometimes occur.

Calabacillo pods are shorter and smoother than those of any other kind of Forastero cacao and terminate in a bluntly pointed tip. Ridges and furrows are not very well defined. The deep purple seeds are very flat and they produce the lowest quality of commercial cacao.

According to Harrison,[30] Calabacillo pods are made up of husk 80.6%, pulp 7.6%, cuticle 1.8% and kernel 10%.

Van Hall[31] gives the following percentage weights of seeds in whole fruit: Java Criollo 21%, Nicaragua Criollo (from Botanical Gardens at Buitenzorg) 36%, Trinidad Angoleta 12%, Trinidad

[28] E. E. Cheesman. *Trop. Agr. (Trinidad), 21,* 144 (1944).
[29] A. F. Posnette, *Trop. Agr. (Trinidad), 22,* 184 (1945).
[30] J. B. Harrison, *Rept. Agric. Sta., Brit. Guiana.* 1897.
[31] C. J. J. van Hall, *Cocoa.* Macmillan, London, 1914.

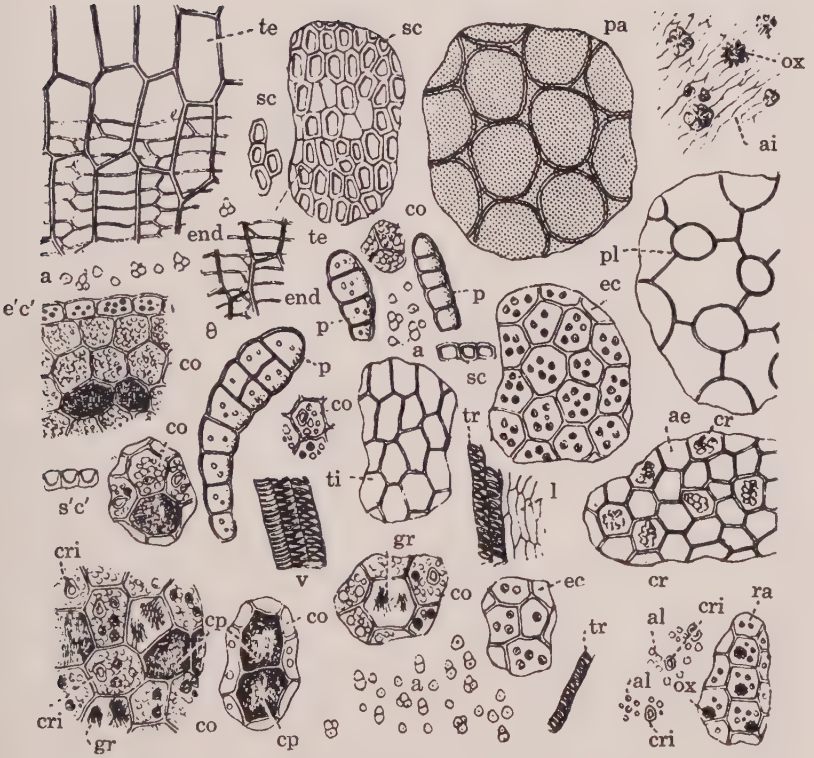


Fig. 7. Microscopical features of cacao seeds. (By courtesy of Messrs. J. and A. Churchill.)

(a) Starch grains
(ae) Outer layer, endosperm
(ai) Inner layer, endosperm
(al) Aleurone grains
(co) Cotyledon
(cp) Pigment cells containing cocoa red
(cr, gr) Fat crystals
(cri) Aleurone grains containing crystals
(ec) Epidermis, cotyledon, surface view
(e' c') Epidermis, cotyledon, profile
(end) Inner epidermis, pericarp
(l) Bast, fibrovascular bundles
(ox) Calcium oxalate crystals
(p) Pluricellular hairs
(pa, pl) Parenchyma, seed coat
(ra) Cells of radicle
(sc) Sclerenchymatous layer, seed coat, surface view
(s' c') Sclerenchymatous layer, seed coat, profile
(te) Outer epidermis, seed coat, to which inner epidermis of pericarp (end) adheres
(ti) Inner epidermis, seed coat
(tr, v) Vessels, etc., from fibrovascular bundles

Cundeamor 15%, San Thomé Amelonado 19% and Surinam Amelonado 23%.

3. Anatomical Structure of Cacao Seeds

The macroscopical features of fresh and fermented cacao seeds are compared in Chapter VI, 7C(1).

The illustration (Fig. 7) of the microscopical appearance of fragments of cacao seeds is due to Greenish and Collin.[32]

The seed coat consists of an outer layer (epidermis) composed of a single layer of polygonal thick-walled cells (te) to which is attached the pericarp, consisting of narrow elongated cells (end) and below this, a layer of parenchymatous cells (pa, pl) containing a row of large mucilage cells and numerous fibrovascular bundles with an abundance of small vessels. The next layer is a single row of small polygonal sclerenchymatous cells (sc). When viewed transversely, these cells resemble horseshoes. The last layer is composed of thin-walled cells.

Surrounding the kernels and lining the folds of the cotyledons is a colourless membrane, the endosperm. Its outer layer (ae) is a single row of large polygonal cells, containing crystals of fat and occasionally crystals of calcium oxalate. The inner layer (ai) is made up of very irregular cells containing fat crystals. Part of the endosperm disappears during fermentation.

The epidermis of cured cotyledons is composed of polygonal cells containing granules of brown pigment and it bears the multicellular hairs (p), but these often break off during processing and are then to be found on the endosperm. The remaining cells of the cotyledons consist of thin-walled parenchyma with spiral vessels. Some of these cells contain very small simple or compound starch grains and aleurone grains embedded in a fatty mass and others contain acicular crystals or crystal aggregates associated with fat and protoplasm. A number of larger cells distributed over the parenchyma of most kinds of cacao cotyledons contain violet or brown pigment.

The parenchyma of the radicle consists of smaller tissue than the cotyledons and is traversed by a vascular system.

The diagnostic characters of cacao seeds are the elongated polyg-

[32] H. G. Greenish and E. Collin, *Anatomical Atlas of Vegetable Powders*. Churchill, London, 1904.

onal epidermal cells of the seed coat crossed by the narrower cells of the inner epidermis of the pericarp; the sclerenchymatous layer of the seedcoat; the cells of the cotyledons containing small starch grains, fat crystals, etc. and the pigment cells; and the remarkable hairs.[33]

Jensen[34] states that the average size of starch grains in commercial cacao is 7μ. The variation is from 2.4 to 12.7μ.

4. Germination Studies

The relative growth rate and net assimilation rate of cacao are much lower than those recorded for other species, and the time which elapses before seedling dry weight exceeds embryo dry weight is exceptionally long. Goodall[35] investigated the early stages in the development of Amelonado cacao seedlings by following dry weight changes from the time of germination until the first flush of leaves had hardened. For the first experiment, ten groups of 25 baskets were filled with topsoil and pairs of seeds from four selections were planted in each. Shade from *Leucaena glauca* reduced illumination to 18% of full daylight. The initial fresh and dry weights of the radicles and cotyledons from four samples of eight beans were determined. After emergence, progress of the seedlings was recorded daily by harvesting seedlings from one basket (selected at random) in each group. When all the plant material had been used up, further experiments were conducted on similar lines, but observations were made on alternate days from the time of planting. By the fourteenth day, half of the plants had emerged. During the initial stages of development, cotyledons of the harvested plants were separated from the radicle and hypercotyl, and the fresh and dry weights of both portions were determined. Sixteen to eighteen days after the seeds were planted, plumules were sufficiently developed to be separated. As growth progressed, leaves and stems were weighed and leaf areas were measured.

At the time of planting, almost 99% of the embryo dry matter is located in the cotyledons and the seedling is entirely dependent on their reserves until three or four days after emergence. The cotyledons then unfold and the food supply is augmented owing to the presence

[33] *Ibid.*

[34] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate, Confectionery and Cocoa.* Churchill, London, 1931.

[35] D. W. Goodall, *Ann. Botany, 13,* No. 49, 1 (1949).

of a little chlorophyll on their upper surface. Between the time of planting and one week after emergence, the dry weight of the seedling decreases by 15% and the embryo dry weight is not surpassed until three weeks later. Relative growth rate is then about 1% per day and the net assimilation rate amounts to 0.90 gram per sq. dm. per week.

Translocation of reserves to the radicle commences three or four days after planting and soon reaches a rate of 19 mg. (13% of the cotyledon dry weight) per day, excluding the amount used by the radicle in respiration. The net loss in dry weight of the cotyledons then proceeds at a fairly constant rate until they are shed, about six weeks after emergence, with 25% to 35% of their original dry weight present.

The rate of increase of dry matter in the root declines when the plumule begins to develop and almost ceases during the third week, when plumular development is most active, but recommences in the fourth week.

After the first week following emergence, the dry matter in the stem increases by 3 to 4 mg. per day.

Leaf expansion commences at the beginning of the second week after emergence. The increase in dry matter reaches a maximum of 20 mg. per day in the middle of the third week and then declines. By the middle of the fourth week, when the first flush is hardening, the increase is negligible and the terminal bud remains quiescent for some weeks before the second flush begins to expand.

During the first five days after planting, the uptake of water is greatest in the cotyledons. Thereafter, a major part of the increase occurs in the root and later in the plumule. The weight of water in the cotyledons begins to decline three weeks after emergence. The uptake of water by the leaves increases rapidly during their development, reaches a maximum in the fourth week after emergence and begins to decline when they are still rapidly expanding. The decline continues during hardening.

CHAPTER III

CULTIVATION

1. Climate

A. ALTITUDE, TEMPERATURE, HUMIDITY

The cacao tree flourishes within the tropics, mainly between the latitudes 20°N. and 20°S. The major part of the crop is grown within 10° of the equator. When essential requirements as to climate and soil are satisfied, the yield increases as the equator is approached.[1]

Cacao is normally cultivated at low altitudes and the bulk of it is produced on land lying within 1000 feet of sea level. While ordinary varieties thrive satisfactorily almost down to sea level, choice varieties respond more favourably above 700 feet. In Ceylon, where the major part of the crop is composed of choice cacao, practically the whole of it is planted at an altitude of over 1400 feet.[2] Van Hall's statement[3] that cacao does not thrive above 1800 feet is refuted by the presence of healthy trees on the slopes of the Andes in Ecuador. Pound[4] calls attention to the fact that fine cacao is grown successfully in sheltered valleys in Colombia at considerably above 3000 feet.

As cacao trees are susceptible to wind, they cannot survive in exposed places. A protective shield of taller trees is therefore essential for their wellbeing. This is provided by leaving a belt of forest trees standing or by planting trees which are especially effective windbreaks.

Cacao needs warmth and a humid atmosphere. The ideal mean shade temperature is 80°F. (26.6°C.) and the range of variation from

[1] H. W. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture.* Churchill, London, 1930.
[2] H. A. Tempany in *Report and Proceedings of the Cocoa Research Conference 1945.* Colonial No. 192, His Majesty's Stationery Office, London, 1945.
[3] C. J. J. van Hall, *Cocoa.* Macmillan, London, 1914.
[4] F. J. Pound in *Report and Proceedings of the Cocoa Research Conference 1945.* Colonial No. 192, His Majesty's Stationery Office, London, 1945.

65°F. to 95°F.,[5] nevertheless, cacao is found in a flourishing condition, in areas of West Africa where the maximum temperature is 104°F. to 105°F. and the relative humidity approaches 100%.[6]

It is frequently cultivated on hillsides along valleys. On sites where the natural supply of water is short, the land must be irrigated. On the other hand, in districts where the rainfall is exceptionally high, a system of drainage is introduced, by digging trenches 1.5 to 2 feet deep on porous soils and appreciably deeper ones for compact soils. In Surinam, where plantations border tidal rivers, protective dykes are constructed to prevent flooding.

B. SHADE TREES

Cacao is usually grown under a shade canopy, formed by the foliage of taller trees. These are distributed either between the rows of regularly spaced cacao trees or at intervals in the same rows. Shade trees are planted in readiness as soon as the plot is cleared, so that they will be effective when the cacao is transplanted from the nurseries. In nurseries where the young trees are raised, temporary shade is obtained by the use of plants of a smaller stature than the permanent shade trees or by erecting screens (Figs. 8, 9, 10).

The reason for introducing shade is that it protects the humus layer of the soil against drying out through exposure to the intense rays of the tropical sun. For the upkeep of available nitrogen, it is advantageous to use leguminous shade trees. An additional benefit is conferred by shade trees in that their leaves contribute litter for the replenishment of the organic matter of the soil. In the layout of shade trees, the aim is to cut down the light by one-half or even three-quarters. Lighter shade is required on hills than on plains. The leaf canopy should never be so dense that it retards photosynthesis nor the roots so prolific that they deplete the soil of nutrients required for the cacao crop.

In Grenada, Nigeria, parts of Brazil and the Dominican Republic, shade is dispensed with after the first three or four years and the soil is protected by closer planting of the cacao trees. This method

[5] E. Montgomery and A. M. Taylor, *World Trade in Cocoa*. U. S. Dept. of Commerce, Industrial Series No. 71, U. S. Govt. Printing Office, Washington, 1947.

[6] O. J. Voelcker in *Report and Proceedings of the Cocoa Research Conference 1945*. Colonial No. 192, His Majesty's Stationery Office, London, 1945.

Fig. 8. Controlled shade experiments, Trinidad: plot of nursery plants growing without shade. The side screen of the 50% shade plot is seen in the background. (Original photograph by R. V. Wadsworth.)

Fig. 9. Controlled shade experiments, Trinidad: plot of nursery plants growing under an artificial canopy giving 50% shade. (Original photograph by R. V. Wadsworth.)

succeeds only when undergrowth is systematically cleared and additional effort is expended in manuring. On the whole, better results are obtained in places where shade is employed.

For shading young cacao, plants which yield crops of economic value are used. Maize, castor beans, cassava and plantain are suitable for this purpose. These plants, known as "catch crops," provide some return before the cacao comes into bearing. Bananas are often chosen, because, by their response, the prospective cultivator is able to determine whether the plot will prove satisfactory for cacao.

Fig. 10. Controlled shade experiments, Trinidad: plot of nursery plants growing under an artificial canopy giving 75% shade. (Original photograph by R. V. Wadsworth.)

In the Gold Coast, silk cotton, capsicum, cassava, plantain and kapok are used for shade. Varieties of *Erythrina*, which in a few years provide an effective canopy, are favoured for permanent shade in Venezuela, Trinidad, Java and Ceylon. On account of their commercial value, rubber trees are planted for shade in some cacao-producing countries.

C. RAINFALL

Although an evenly distributed rainfall of at least 50 inches per annum and the maintenance of a high humidity are regarded as essentials, there are tracts in Nigeria and the Gold Coast with a rainfall of only 45 inches, where cacao is successfully cultivated.[7] While 60 to 80 inches are desirable, 80 to 100 inches are not necessarily excessive and even 125 inches can be tolerated on certain types of soil, provided that the roots are not waterlogged. The attendant dangers of high rainfall are soil erosion and the maintenance under the leaf canopy of a humidity so excessive as to favour the development of fungal diseases.[8]

Drought is an enemy of cacao. Reckless deforestation has reduced the rainfall in some areas of West Africa to a level which is adversely affecting production.

2. Soil

A. GENERAL STRUCTURE

The solid matter of soil is composed of inorganic material originating from the parent rock and organic matter derived from decaying vegetable litter and the excreta of animals. Only about one-tenth of the mineral nutrients of the soil is immediately available, because the particles are protected against leaching by a film of colloidal matter on which small quantities of loosely held nutrients are adsorbed. The breakdown of litter is an important factor governing the liberation of nutrients and conservation of moisture. Humphries and Rodrigues[9] state that decomposition of the litter of cacao leaves is very rapid under natural tropical conditions and that the rate scarcely differs in wet or dry seasons. In the course of decomposition, there is a net increase of lignin, resistant protein, acid-hydrolysable protein fractions and nitrate nitrogen. Hemicellulose, cellulose and pentosans decrease fairly rapidly in the initial stages. Alcohol-

[7] H. A. Tempany in *Report and Proceedings of the Cocoa Research Conference 1945.* Colonial No. 192, His Majesty's Stationery Office, London, 1945.

[8] E. E. Cheesman, *Report on the Potentialities for the Cultivation of Cocoa in Mayala, Sarawak and North Borneo.* Colonial No. 230, His Majesty's Stationery Office, London, 1948.

[9] E. C. Humphries and G. Rodrigues, *J. Agr. Sci., 35,* 247 (1945).

and ether-soluble materials diminish rapidly during the first few weeks. At the beginning potassium decreases quickly and the subsequent trend is similar to that of alcohol- and ether-soluble substances. At times of heavy leaf fall, the manurial effect may be equivalent to 1 cwt. of potassium sulphate per acre.

Water-retention is determined by the capillary pore space. Noncapillary pore space facilitates drainage. If drainage is free and noncapillary pore space good, sufficient oxygen is available to the roots.[10] When waterlogging occurs, anaerobic conditions prevail and the roots are unable to function properly. Prolonged submersion causes susceptibility to fungal invasion.

Chenery and Hardy[11] measured the moisture profiles of cacao soils in Trinidad to a depth of six feet. Observations were made at two-monthly intervals over a period of 14 months. Three sandy soils showed adequate or excessive aeration but poor moisture retention. Two calcareous silty soils became waterlogged during rains but rapidly recovered in dry weather. Penetration was somewhat restricted in the case of two clayey silts. Three non-calcareous alluvial silty clay soils were adequately aerated throughout the litter layer only. During the rainy season, the profile was almost saturated with water.

B. AERATION

By determining the moisture, dry matter and true specific gravity of the soil in samples withdrawn by means of a constant-volume soil borer, Hardy[12] was able to estimate the free air space in Trinidad cacao soils and to follow the fluctuations in the amount of soil air during a complete growing cycle. Free air space values of less than 12% of the total volume of the soil are associated with restricted diffusion and the development of anaerobic conditions. In wet periods, anaerobic conditions develop to the greatest extent on clay and least on sand. As cacao seed growth and reproduction occur mainly during the wet season, productivity is retarded during lengthy spells of inadequate aeration, owing to elimination of free air space or accumulation of toxic amounts of carbon dioxide.

Vine[13] compared the aeration of cacao soils by their power of

[10] G. W. Dimbleby, *Chemistry and Industry*, 360 (1948).
[11] E. M. Chenery and F. Hardy, *Trop. Agr. (Trinidad), 22*, 100 (1945).
[12] F. Hardy, *Trop. Agr. (Trinidad), 20*, 13 (1943).
[13] H. Vine, *Trop. Agr. (Trinidad), 20*, 51 (1943) ; *20*, 89 (1943)

corroding iron spikes exposed for six weeks at different levels. This method is only satisfactory for soils with pH values above 4.3. For lower pH values, acid is a factor in the amount of corrosion. Soil corrosiveness decreases with depth, corresponding to decrease of oxygen supply. As might be expected, high productivity was found to be related to good aeration.

C. NITROGEN METABOLISM

Nitrogen for the maintenance of plant life is rendered available in the form of nitrates as a result of the enzymic decomposition of nitrogenous organic matter. Lees[14] has described the effects of percolation of the crumb layers of a good and a bad cacao soil with casein solutions. Nitrification of ammonium ions appears to be quicker in good soil and mineralisation of nitrogen from organic combination proceeds more rapidly in bad soil. Sodium azide is a more effective poison in a poor soil because it combines with and immobilises trace elements.

Atmospheric nitrogen fixation by *Rhizobium,* living in symbiotic association with legumes, is of some interest in connection with cacao culture, because the nitrogen status of the soil is enhanced by the litter from leguminous shade trees. *Rhizobia* penetrate the tissue of the host plant through the root hairs, causing their deformation and the development of root nodules containing haemoglobin, which is actively associated with symbiotic nitrogen-fixation.

D. ROOT-STIMULATING COMPOUNDS

Rhizobia are believed to be capable of producing the root-stimulating plant hormone, indoylacetic acid. Indoyl compounds have been used to promote root development on cacao cuttings. During trials on cuttings at the West African Cacao Research Institute, it was shown that β-indoylbutyric acid was especially effective. When talc containing 0.5% of the stimulant was administered, successful rooting occurred on 74% of the cuttings, an improvement of up to 30% over controls. A concentrated application for one second was found to be as effective as a dilute dip for 24 hours.[15]

[14] D. H. Lees, *Report on the Cocoa Conference, 1949,* 24. The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1949.
[15] Anon., *Ann. Rept. West African Research Institute (1945–46),* 49.

E. MYCORRHIZAE

When a specific fungus proliferates on the roots of a plant to the mutual benefit of both fungus and host, the association is described as mycorrhizal. Laycock[16] has drawn attention to a phycomycetous endotrophic mycorrhiza found on cacao roots in Trinidad, Tobago and Venezuela. It appears to be especially prolific on poor plots. Attempts to isolate the fungus in pure culture have not been successful. The exact significance of its presence has not yet been established, nor is it certain whether its function is of any particular importance, as cacao seedlings can grow for at least fifteen weeks without mycorrhizae. Possibly mycorrhizae increase the rate of metabolism when the soil is low in nutrients.

F. INORGANIC NUTRIENTS

Nitrogen, phosphorus, potassium, calcium, magnesium and sulphur are required in relatively large amounts by most crops. Iron, manganese, boron, copper, zinc and other elements are necessary in relatively smaller amounts. Roots are able to exchange their carbonic acid for cations contained in soil colloidal matter. The amount of available phosphorus depends on colloidal (clay) matter and pH. When the soil is mainly clay and strongly acid, phosphorus is immobilised by iron and aluminum and is released by lime. For sulphur, the plant depends partly on inorganic salts and partly on organic matter. Excesses of certain elements can be equally injurious to the plant as deficiencies. Immobilisation of iron by excess of calcium causes chlorosis. Iron deficiency can also be induced by excesses of manganese, zinc, copper, cobalt, or nickel.[17] Greenwood and Posnette[18] have drawn attention to a case of cacao leaf deformation as a result of lack of iron and manganese in heavily limed soil. Alkaline surface soils in West Africa may give rise to sickle leaf disease (see Chapter IV) which is believed to be due to inability of the soil to provide traces of zinc for normal growth.[19]

Retention of trace elements by the soil is related to their power of forming organic complexes and thereby allowing a sufficiently grad-

[16] D. H. Laycock, *Trop. Agr. (Trinidad), 22,* 77 (1945).
[17] C. R. Millikan, *Nature, 161,* 528 (1948).
[18] M. Greenwood and A. F. Posnette, *Nature, 159,* 542 (1947).
[19] C. F. Charter, *Report on the Cocoa Conference, 1949,* 105. The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1949.

ual but continuous supply to the plant. Lees,[20] reporting on the copper-retaining power of different cacao soils, established that it is related, but not linearly, to the organic matter content of the soil. Poor soils are characterized by low copper-retention. Depletion of trace elements from soils exploited by cacao growers is the probable cause of reduced yields.

In Grenada and Trinidad, soils which give high yields of cacao are richer in manganese than those which give low yields. In Tobago, the reverse is true. Cacao leaves from plants grown on non-gypseous alluvial clay soils contained 24 times as much manganese as leaves of plants from highly gypseous Brasso clay of low manganese content. Manganese deficiency appears to be a contributory factor to low yield of cacao on certain gypseous soils in Trinidad. The low manganese content of such soils may be a cause of their failure to respond to phosphate fertilizers.[21]

Sodium and chlorine are not essential to most crops. The membranes of root tissue are sometimes completely impermeable to sodium.[22] Van Hall states that cacao trees in Surinam and San Thomé, where coastal plantations are often flooded at high tide, can tolerate a fair amount of salt because they have become adapted to the prevailing conditions.[23] On the other hand, cacao grown on soil containing only traces of salt is soon injured when flooding from tidal rivers occurs.

G. CRITERIA FOR CACAO SOILS

Hardy[24] describes the organic profile of cacao soils as a surface layer of fresh litter of leaves, flowers and twigs, covering a layer of partially decayed litter of still recognisable structure below which are fragments of blackened leaves and woody matter interwoven with fungal mycelia and insect refuse, and closely associated with fibrous tree roots. In the crumb below the litter which is exploited by the ramifications of fibrous roots, aggregates are formed by the binding action of viscous organic matter. The crumb may be merged with friable humic soil, though sometimes the two layers are distinct. In

[20] H. Lees, *Biochem. J., 43,* 624 (1948).
[21] J. McDonald and G. Rodriguez, *5th Ann. Rept. Imp. Coll. Trop. Agr. (Trinidad),* 43 (1935).
[22] H. Lundegårdh, *Nature, 157,* 575 (1946).
[23] C. J. J. van Hall, *Cocoa.* Macmillan, London, 1914.
[24] F. Hardy, *Trop. Agr. (Trinidad), 21,* 184 (1944).

clay soils, the non-capillary pore space is greatest in the crumb layer and diminishes with depth.

Cacao soils should be relatively high in colloid content. Their nutrient status depends on the depth of the organic layer, and the chemical composition of the soil organic matter is influenced by the composition of the parent rock, on account of the transfer of nutrients through the soil by the growing plant. Acidity is indicative of nutrient deficiency. In soils having an acid layer below the humus, root distribution is restricted. Solid rock should not be less than five feet below the surface of the soil, so that ample space is allowed for root development.

For properly balanced nutrition, the proportions of nitrogen, phosphorus and potassium developed under tropical rain forest should be preserved. This balance may be realised without manuring only if the rocks are readily weathered and the supply of litter is adequate. A tentative classification of sandy and clay soils in Trinidad is given in Table I. Soils below medium status are unsatisfactory for cacao cultivation.[25]

TABLE I. Provisional Nutrient Standards for Trinidad Cacao Soils[a]

Nutrient status	Total nitrogen, %		Available phosphate, p.p.m.		Available potash, exchangeable K_2O, p.p.m.	
	Sands	Clays	Sands	Clays	Sands	Clays
High.....	0.30	0.40	75	125	200	330
Medium-high.	0.20–0.30	0.25–0.40	45–75	75–125	140–200	225–330
Medium.....	0.15–0.20	0.20–0.25	30–45	50– 75	110–140	175–225
Medium-low..	0.10–0.15	0.15–0.20	15–30	25– 50	80–110	125–175
Low.....	0.05–0.10	0.10–0.20	7–15	12– 25	45– 80	75–125
Very low.....	— 0.05	— 0.10	— 7	— 12	— 45	— 75

[a] F. Hardy in *Report and Proceedings of the Cocoa Research Conference 1945.* Colonial No. 192. His Majesty's Stationery Office, London, 1945.

Cacao soils should have a relatively high C:N ratio as well as the amount of total nitrogen indicated for medium to highly nutrient soils. Cacao grown under shade requires a higher proportion of potassium, as this element plays an important role in photosynthesis. Colloidal humus possesses the power of fixing large amounts of potash. Sandy soils with low humus content are unsatisfactory for cacao.

[25] F. Hardy in *Report and Proceedings of the Cocoa Research Conference, 1945.* Colonial No. 192. His Majesty's Stationery Office, London, 1945.

The best cacao soils are potash-rich alluvial absorptive clays and volcanic ash or volcanic agglomerate with fairly high potash content, derived from intermediate magmas (diorite or syenite). In West Africa, the major part of the cacao crop is grown on earths derived from acid igneous intrusions. Of these, the most productive are grandiorites and gneisses, consisting of quartz, potash, soda and soda-lime felspars, biotite and hornblende.[26] Granites, containing quartz, felspars (mainly of potash), biotite and muscovite, on weathering produce quartz sand and non-shrinking, non-absorptive clay. Unless their base-exchange capacity is raised by a high humus content, granites and granite-gneisses are not ideally suited for cacao.

Satisfactory soils, mentioned by Hardy,[27] are greensands, such as the glauconitic rocks forming Chocolate Soil, Brasso Sand and part of the Brasso Clay in Trinidad, soils derived from marl stones and marly clays, except where they are sufficiently weathered to expose calcareous parent rock and thereby diminish the availability of the potash, and certain metamorphic rocks in the form of finely grained schists rich in potash and low in quartz.

Examples of these are the mica-talc schists of Trinidad and some of the phyllites of West Africa. The mechanical structure of the latter is good and they have acquired their fertility from the layer of forest humus. Acquired fertility of soils whose parent rocks are lacking in nutrients is not sufficiently permanent to support the crop over a long term of years.

H. FERTILIZERS

The nutrient status of soils which are not inherently fertile can only be properly maintained by regular applications of fertilizers. Organic fertilizers are mainly concerned with improvement of structure and make but a small contribution to the nutrient value of the soil. Chemical fertilizers are necessary for the upkeep of mineral nutrients. Suitable fertilizers for tropical agriculture recommended by van Hall[28] are as follows:

[26] Anon., *West African Cacao Research Institute Ann. Report. 1945–46,* 39 (published 1947).

[27] F. Hardy in *Report and Proceedings of the Cocoa Research Conference 1945.* Colonial No. 192. His Majesty's Stationery Office, London, 1945.

[28] C. J. J. van Hall, *Cocoa.* Macmillan, London, 1914.

Organic: Farmyard or pen manure, compost, mulch.

For phosphorus and nitrogen: Bone dust and Peru guano.

For phosphorus only: Basic slag and superphosphate.

For nitrogen only: Ammonium sulphate, dried blood, Chile saltpetre.

For potash: Potassium sulphate and kainit.

For lime: Quicklime and calcium carbonate.

On small cacao farms, a sufficient supply of pen manure can be assured by keeping animals alongside the plot. For use on large plantations, Whymper[29] recommends a balanced mixture of horse manure with sodium nitrate, bone ash superphosphate or dried blood.

Hart[30] draws attention to the importance of mulching which provides nutrients, keeps down undergrowth and attracts earthworms to assist aeration. For application, he advises a distance of at least 12 inches from the stems of young plants, so that the mulch lies immediately over the area of the soil where root hairs are most prolific. For older trees, the distance should be increased to four feet.

Hardy[31] states that artificial nitrogen fertilizers may be useful for soils lacking organic matter. Periodical application is required to maintain a steady supply of available nitrogen. The proper balance of nutrients is important. In the presence of adequate phosphate, potassium reduces nitrogen uptake. Excessive lime may seriously affect the nutrient balance with respect to both potassium and nitrogen.

Experiments conducted at the West African Cacao Research Institute showed that cacao plants receiving an excess of nitrogen soon exhibited leaf necrosis, first at the tip and later towards the centre. Such symptoms are usually associated with deficiency of potassium.[32]

I. pH OF CACAO SOILS

High yielding West African soils over granite rock are neutral or only slightly alkaline in the surface layer and become progressively more acidic until the decomposition layer over the parent rock is

[29] R. Whymper, *Cocoa and Chocolate, Their Chemistry and Manufacture,* 2nd ed. Churchill, London, 1921.

[30] J. H. Hart, *Cacao.* Duckworth, London, 1911.

[31] F. Hardy in *Report and Proceedings of the Cocoa Research Conference 1945.* Colonial No. 192. His Majesty's Stationery Office, London, 1945.

[32] Anon., *17th Quarterly Rept. West African Cacao Research Institute,* July–Oct. 1948.

reached. Here the pH is 4.5. Soils with a pH value of 4.0 or less in the humic zone are unsuitable for cacao.[33]

TABLE II. pH Values of Some Trinidad Cacao Soils[a]

	Soil depth, inches							
	0–4		4–8		8–12		24–28	
	% Sand	pH	% Sand	pH	% Sand	pH	% Sand	pH
Very productive. Dark brown stony sand, uniform to a depth of 3 ft.....	48	7.1	52	7.1	54	6.6	55	5.9
Fairly high productivity. Dark brown crumbly soil, compact below 4 in., gravel below 24 in.....	60	6.7	60	6.2	60	5.9	60	4.9
Fairly high productivity. Alluvial, compact, fine loamy sand.....	42	5.8	44	5.5	41	5.7	46	5.9
Low productivity. Sandy surface, impervious clay below.	44	5.4	39	5.1	21	5.0	23	4.8
Low productivity. Badly drained alluvial flat, with compact clay in surface layer	6	4.9	5	4.9	6	4.8	5	5.1
Low productivity. Badly drained flat; one inch humic layer contaminated with thrown-up drain bottom soil	4	4.4	2	4.7	3	4.8	3	5.1

[a] H. Vine, *Trop. Agr. (Trinidad), 20,* 51 (1943).

Table II[34] illustrates the relationship between pH value and productivity established by Vine who used a glass electrode for measurements at different depths on six different types of Trinidad cacao soils and thus demonstrated that a pH range of 6 to 7 in the top 12 inches of soil is associated with high and medium-high productivity.

J. PRODUCTIVITY

Yield depends on the fertility, texture and depth of the soil. Other factors affecting production are rainfall, spacing, age of tree,

[33] C. F. Charter, *Report on the Cocoa Conference 1949,* 105. The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1949.
[34] H. Vine, *Trop. Agr. (Trinidad), 20,* 51 (1943).

whether it is self-sterile, or self-fertile, its adaptability to different environments and degree of resistance to disease.

The most productive cacao soils are sites which have recently supported semi-evergreen or evergreen lowland forest. As the root mat arising from laterals rapidly exhausts the organic layer, the establishment of cacao on intrinsically good land which has previously been heavily food-farmed can only be assured if the soil is regenerated by a few years under shade and bush vegetation. A striking illustration of the importance of humus upkeep is shown by the yields on two plots at the West African Cacao Research Institute after eight years' cultivation.[35]

A. Land dug over and clean cultivated. Cassava and plantains interplanted with cacao seedlings. After harvesting the cassava, the weeds were kept cutlassed.

Result: Many vacancies, average height of cacao four feet, yield nil in 1948.

B. Land dug over and clean cultivated. Cassava and *Gliricidia* (shade tree) planted through cacao seedlings. Bush vegetation was encouraged to grow after harvesting the cassava.

Result: No vacancies, average height of cacao 20 feet, yield 1523 pods in 1948.

Production is measured by the number of pounds of dry cacao beans per acre. The average number of dry cured beans per pound is 450 in Grenada and Pará, 410 in Bahia, 380 in West Africa, Trinidad and Ceylon, 350 in Caracas, 330 in Machala and 300 in Arriba and Carupano.[36] The number of pods required to produce 1 lb. of dry cacao depends on pod size, thickness of wall and how closely the beans are arranged. For Trinitarios, it may be seven or less, for Ecuador Nacional ten and for pure Criollo 12 or 13.[37]

Bowman[38] considers that an average yield of 2000 lb. of dry cacao per acre should be possible by selection. During the season 1931–32, 1800 lbs. of dry cacao per acre were recorded on a native farm in Nigeria.[39]

[35] O. J. Voeleker, *W.A.C.R.I. 1944–49* (p. 12 in typescript), West African Cacao Research Institute, Tafo, Gold Coast, undated.
[36] A. W. Knapp, *Cocoa and Chocolate*. Chapman and Hall, London, 1920.
[37] G. F. Bowman, *Cacao Information Bull., 1,* No. 20, 1 (1949).
[38] *Ibid.*
[39] J. West in *Report and Proceedings of the Cocoa Research Conference 1945.* Colonial No. 192, His Majesty's Stationery Office, London, 1945.

Yields from unselected Amelonado of approximately 600 stands per acre were recorded for the seasons 1941–42 to 1944–45 at a typical group of native Nigerian farms on good Ilepa clay. The original planting dates were estimated and the estimates agreed with girth measurements. The average annual yield for trees planted between 1931 and 1935 was 561 lb.; 1926 to 1930, 635 lb.; 1921 to 1925, 825 lb. and 1916 to 1920, 630 lb. of dry cacao per acre.

The effects of different spacing distances were assessed by the average yields from trees planted at 8 x 8 ft., 12 x 12 ft. and 15 x 15 ft. on each of six experimental plots in Nigeria. The soils ranged from poor sandy types to good Ilepa hilltop clay. For six-year old trees, the average yields of dry cacao per acre were 55 lb. at 8 x 8 ft., 5 lb. for 12 x 12 ft. and 8 lb. at 15 x 15 ft. For eight-year old trees, the corresponding yields were 296, 80 and 79 lb., and for ten-year old trees 346, 130 and 126 lb. respectively. The best individual plots in the tenth year were 831 lb. at 8 x 8 ft., 329 lb. at 12 x 12 ft. and 303 lb. at 15 x 15 ft. For two additional one-acre plots at 8 x 8 ft. on good Ilepa clay, the average yields were 51 lb. at six years, 289 lb. at seven years, 386 lb. at eight years, 540 lb. at nine years and 632 lb. at ten years.[40]

Five grades of cacao land recognized in Trinidad and Tobago are: I, very high productivity, yielding over 500 lb. of dry cured beans per acre in the peak productivity period; II, high productivity, 350–500 lb.; III, medium productivity, 165–350 lb.; IV, low productivity, 85–165 lb. and V, very low productivity, below 85 lb.[41] Elsewhere, grade II is described as yielding from 330 to 500 lb.[42]

The chemical and physical characteristics of nine Trinidad cacao soils which lie in the first three grades are presented in Table III. The soils were examined by Hardy and co-workers[43] in an attempt to correlate root morphology, penetration and distribution with physical and chemical properties of soils, particularly with reference to the depth of humic layer and content of nitrogen, avail-

[40] J. West in *Report and Proceedings of the Cocoa Research Conference 1945.* Colonial No. 192, His Majesty's Stationery Office, London, 1945.

[41] E. M. Chenery in *Report and Proceedings of the Cocoa Research Conference 1945.* Colonial No. 192, His Majesty's Stationery Office, London, 1945.

[42] C. W. R. McCreary, J. A. Macdonald, V. I. Mulloon and F. Hardy, *Trop. Agr., (Trinidad), 20,* 207 (1943).

[43] C. W. R. McCreary, J. A. Macdonald, V. I. Mulloon and F. Hardy, *Trop. Agr. (Trinidad), 20,* 207 (1943).

TABLE III. PRODUCTIVITY AND PROPERTIES OF CACAO SOILS[a]

Grade	Av. yield, lb./acre dry cacao	Thickness of main rooting zone, inches	Humic soil		Top 12 inches layer of soil					
			Depth, inches	Av. organic matter, %	Index of texture	pH	Organic matter, %	Total nitrogen, %	Available P_2O_5, p.p.m.	Available K_2O, p.p.m.
3	200	8	6	1.4	38	5.6	0.9	0.09	39	101
3	240	12	7	2.8	46	5.5	1.9	0.13	11	74
3	250	12	8	2.8	25	6.0	2.1	0.15	13	88
2	330	20	16	0.8	28	4.9	1.0	0.10	6	57
2	400	20	18	1.7	22	6.2	2.1	0.15	20	55
2	450	22	15	2.5	56	6.7	3.5	0.24	14	169
1	500	12	12	4.0	28	6.4	4.0	0.27	28	219
1	550	12	12	4.7	24	7.6	4.7	0.20	—	—
1	650	20	18	1.7	41	6.7	2.0	0.17	48	140

[a] C. W. R. McCreary, J. A. Macdonald, V. I. Mulloon and F. Hardy, *Trop. Agr. (Trinidad), 20,* 207 (1943).

able potassium and phosphorus. The available potassium is represented as exchangeable K_2O with $N/2$ acetic acid. The pH values were determined by quinhydrone electrode on soil diluted with 2.5 parts of water. Index of texture was calculated by subtracting one-fifth of the content of coarse and fine sand (2.0–0.02 mm.) from the sticky point value. This gives a measure of the degree of clayeyness. Values range from 60 for heavy clay down to zero for light sands.

As might be expected, high yield is associated with good supplies of mineral nutrients and high pH, but the productivity of these soils appears to bear surprisingly little relationship to their humic content. It is possible that the soil giving the maximum yield will soon show a decline in productivity unless it is replenished as described in example B above.

3. Planting

Cacao is propagated either from seed or vegetatively from buds or cuttings. Seeds may be planted at stake in their permanent position or reared in nurseries and transplanted. Cuttings are placed in propagators until they have rooted and when the rootlets have hardened the plants are transferred to nurseries until they are sufficiently well established for plantation in the field.

A. SELECTION OF SEED

To find the best trees from which to obtain seed, van Hall[44] recommends that records of bearing power, hardiness and quality should be kept over a number of years. Seeds should be taken from mature pods and only the largest ones used. Terminal seeds are always smaller and should therefore be rejected.

B. SOWING

Before sowing the seeds, any adhering pulp can be removed by rolling them in dry earth, ash or lime. Some growers remove the testas before planting seed. The behaviour of alternate rows of skinned and unskinned seeds has been investigated by Escamilla, Paredes and von Buchwald.[45] The skinned seeds germinated more rapidly than the whole seeds.

[44] C. J. J. van Hall, *Cocoa*. Macmillan, London, 1914.
[45] G. Escamilla, L. A. Paredes and A. von Buchwald, *Cacao Information Bull., 1*, No. 16, 3 (1949).

The system described by Hart[46] for nursery planting is to sow the seeds in groups of three, six inches apart, in triangular formation, with a space of 12 inches between each group. The seeds are placed about one inch below the surface, in ground previously treated with manure during the dry season. A second application of manure is desirable when the seedlings are six inches high and the first pair of leaves has appeared.[47] During drought, seedlings should be watered after germination.

The practice of planting three seeds, rejecting two and retaining the one which shows the best performance, has been criticised as wasteful. It has recently been suggested that wastage can be prevented by sowing single seeds, 12 inches apart, in beds covered with banana leaves giving 50–60% of shade. The seeds, with testas removed, are planted base downwards and the apex is on a level with the surface of the ground.[48]

When planting at stake, it is usual to sow in groups of three seeds and later to thin out by removing the less healthy plants. In Nigeria, seeds are sown at intervals of 4 x 4 feet and thinned out to 8 x 8 feet when the cacao comes into bearing.

All young cacao trees are grown under temporary shade plants or else protected by an artificial canopy made from palm leaves. As a precaution against fungus diseases, it may be advisable to spray the trees with Bordeaux mixture.

C. TRANSPLANTING

Nursery plants are ready for transplanting when they have attained a height of about two feet.[49] If the soil is stiff, the roots are excavated together with a lump of soil of about 12 inches in diameter. This is retained when placing the plants in their permanent position. If they are taken from loose soil, the roots are washed to remove the bulk of it and the hole prepared for receiving them is afterwards filled with rich friable soil. Nursery plants are sometimes grown in pots or baskets. In such cases, transplantation is effected with less risk of damage to the roots. In Nigeria, losses by digging are at least

[46] J. H. Hart, *Cacao*. Duckworth, London, 1911.
[47] C. J. J. van Hall, *Cocoa*. Macmillan, London, 1914.
[48] Anon., *Cacao Information Bull., 1,* No. 14, 2 (1948).
[49] R. Whymper, *Cocoa and Chocolate, Their Chemistry and Manufacture,* 2nd ed. Churchill, London, 1921.

50%. With basket seedlings, observes losses were as low as 7% on good soils and up to 35% on sandy soils.[50]

D. SPACING OF TREES

Whether planted at stake or transplanted, cultivated cacao trees are generally arranged in rows at regular intervals. Spacing distances may be from 8 x 8 feet up to 15 x 15 feet, according to the accepted custom of the country, quality of soil and whether any system of permanent shade is used. Wider spacing facilitates pruning, weeding, spraying and harvesting. According to experiments in the field by Baker and Dale,[51] closer planting tends to reduce pod infection by witches' broom and other diseases. Spacing distance of 8 x 8 feet was found to be most satisfactory for minimising pod infection.

E. VEGETATIVE PROPAGATION

Hart[52] succeeded in propagating cacao vegetatively by means of grafting by approach. Although grafted trees bear earlier than those grown from seed, Hart's method is too cumbersome for large scale propagation and was superseded by budding, which, however, suffers from the disadvantages that the characteristics of a selected tree may sometimes fail to be transmitted to its budded offspring. A method of propagation by cuttings, devised by Pyke[53] and elaborated by Cheesman and Spencer,[54] is used in Trinidad for the production of clonal rootstock material. The term "clone" embraces all the vegetatively propagated stock from one selected parent tree, which may eventually represent an enormous number of individual trees, although they are actually only parts of the original tree. Cacao cuttings can be taken either from branches as they fan out (fan branches) or from suckers (chupons).

Montserin[55] states that fan cuttings taken from vigorous plants grown under nursery conditions yield higher rooting percentages

[50] J. West in *Report and Proceedings of the Cocoa Research Conference 1945.* Colonial No. 192, His Majesty's Stationery Office, London, 1945.
[51] R. E. D. Baker and W. T. Dale, *Trop. Agr. (Trinidad), 21,* 170 (1944).
[52] J. H. Hart, *Cacao.* Duckworth, London, 1911.
[53] E. E. Pyke, *1st Ann. Rept. on Cocoa Research, Imp. Coll. Trop. Agr. (Trinidad),* 4 (1932).
[54] E. E. Cheesman and G. E. L. Spencer, *5th Ann. Rept. on Cocoa Research, Imp. Coll. Trop. Agr. (Trinidad),* 4 (1936).
[55] B. G. Montserin, in *Report and Proceedings of the Cocoa Research Conference 1945.* Colonial No. 192, His Majesty's Stationery Office, London, 1945.

than old bearing trees. The proper time to take cuttings is immediately the leaves have hardened after a vigorous flush. A suitable cutting should have from 9 to 15 inches of new growth and be green for about three-quarters of its length. Cuttings measuring one inch more than the desired length are taken between 7 a.m. and 9 a.m. The apical halves of the upper leaves are cut off to reduce transpiration and the entire leaves are removed from the lower half of the stem. The extra inch of stem is then cut off and the newly exposed stem is immersed in a hormone solution. The stimulant giving the best results in the Gold Coast is β-indoylbutyric acid (see Chapter III, 2D). Naundorf[56] compared the stimulating effects of (*a*) 0.4% solution of α-naphtheneacetic acid, (*b*) 0.4% γ-indoylbutyric acid in talc applied to the base of cuttings, (*c*) 0.2% solution of α-naphtheneacetic acid applied to incisions made near the base of cuttings and (*d*) a paste containing 25% of α-naphtheneacetic acid spread over incisions made in branches a week before the cuttings were taken. Treatments *b* and *c* resulted in the most rapid rootings and treatment *a* gave the poorest results.

Immediately after dipping, cuttings are set seven to nine inches apart and about four inches deep in the sand of a propagator and watered at once. They are watered three or four times daily for four weeks, by which time the root system should be well developed.

The rooted cuttings are carefully removed from the sand and the roots are rinsed in water before being transferred to a mixture of soil and compost in pots or baskets. The plants are watered before being placed in bins where they undergo a hardening process under controlled humidity and shade. Humidity is gradually decreased and light increased until hardening is complete (about 14 days). Trinitario cuttings show a higher percentage of rootings than Amelonado cuttings. For a time, the shoots of fan cuttings display a tendency to fan out and the roots to develop horizontally. The shoots and roots from chupons grow vertically and produce better shaped trees. Propagation by chupons is limited by the amount of material available. Fan cuttings, on the other hand, are usually easier to obtain in quantity.

A simple propagating bed for cuttings, in which it is possible to obtain about 80% of rootings, is described by Bowman.[57] The lay-

[56] G. Naundorf, *A Contribution on Vegetative Propagation.* Estacion Experimental Agricola, Palmira, Colombia; *Cacao, 2,* No. 7, 5 (1950).
[57] G. F. Bowman, *Cacao Information Bull., 1,* No. 5, 1 (1948).

out is a shallow ditch with a good outlet. Gravel is placed in the ditch and covered with a 91 to 10-inch layer of clean sand, supported if necessary by boards. Cuttings are dipped in stimulant and placed in the sand, allowing an area of 16 sq. in. for each. A gentle spray of water is then trained on the ditch. No shade is required. After three or four weeks, rooted cuttings are planted in a raised, shaded bed of ordinary soil and sprayed for six to eight days. The duration of spraying is gradually reduced to one hour at midday. The plants are grown in a nursery bed for one to four months before transplantation to the field.

When material from older trees is used, propagation by budding is easier than from cuttings. One bud put on a vigorous chupon may yield 20 cuttings in six months. A three-bud rooted cutting requires 18 months to produce 20 cuttings.[58] Budwood is more easily transplanted than cuttings, and occupies less space.

Escamilla, Paredes and von Buchwald[59] report 25% success and less rapid growth from dormant buds and 75% success accompanied by more vigorous growth by using buds prepared from six- or seven-month old twigs or 12-month old chupons arising from the trunk or main branches of cacao trees. Leaves are cut while still on the tree, leaving a small piece of petiole on each bud and the apex is cut off just above the last bud. After eight to ten days, when the petioles fall off, the stick is removed from the tree. Budstick should be of the same diameter as the stock. When chupons are used as stock, the bud should be placed as near to the base as possible and preferably on basal chupons. On seedlings, the bud should not be more than 10 cm. above ground. Incisions are made in the stock, in the form of an inverted U. A bud of matching size is inserted in the tongue, part of which is then cut off, so that the bud is not enveloped. Care must be taken to secure an intimate contact between the cambium layers, because phloem tissue is the site of origin of *leptohormones* which determine the rate of cellular division.[60] The tongue and bud are then covered with a loose but firm wrapping and the stock is cut off 10 cm. above the bud. After eight days, the wrap is partially removed to allow sprouting.

[58] G. F. Bowman, *Cacao Information Bull., 1,* No. 20, 1 (1949).
[59] G. Escamilla, L. A. Paredes and A. von Buchwald, *Cacao Information Bull., 1,* No. 16, 3 (1949).
[60] L. A. Paredes, *Cacao Information Bull., 1,* No. 21, 5 (1949).

By statistical trials at River Estate, Trinidad, it has been shown that there is a general superiority of cuttings over buddings on seedling rootstock, especially in good clones. The difference is less marked as the tree matures. With the exception of one selection, no intrinsic differences were observed between fan and chupon cuttings.[61]

4. Pruning

Hart[62] advises pruning young trees lightly every month to allow the development of a large area of healthy leaf surface, always having under consideration the relation between horizontal extension of branches and lateral spread of roots. The angle of the cut should be such that the stump of the branch is able to shed rainwater instead of retaining it. A tar dressing should be applied to the newly exposed surface. For young trees with a single shoot, Whymper[63] recommends that not more than four small branches should be allowed to form and that secondary or tertiary branches should be induced to grow at regular intervals. In the early stages, it is preferable to prune the wood while it is still sufficiently soft to be pinched rather than cut. The time for pruning older trees is after harvesting. For cleaning-up operations, van Hall[64] considers it advisable to remove not only the weak and unhealthy twigs, but all the chupons. In some countries, it is customary to leave the chupons round the base so that the healthiest can be selected to replace the parent tree when its bearing is no longer profitable. According to van Hall, it is only admissible to allow one chupon to develop when a tree has sustained injury.

Concerning dressings, Briton-Jones[65] advises careful application, so that the power of the tree to heal its scar will not be impaired.

Shade trees also may require thinning to reduce humidity and allow access of sufficient light to the crop.

The effects of different degrees of pruning were determined from the response shown by 42 Amelonado trees of seedling origin grown

[61] F. W. Cope, *Report on the Cocoa Conference 1949*, 86. The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1949.
[62] J. H. Hart, *Cacao*. Duckworth, London, 1911.
[63] R. Whymper, *Cocoa and Chocolate, Their Chemistry and Manufacture*, 2nd ed. Churchill, London, 1921.
[64] C. J. J. van Hall, *Cocoa*. Macmillan, London, 1914.
[65] H. R. Briton-Jones, *The Diseases and Curing of Cacao*. Macmillan, London, 1934.

in Costa Rica.[66] When stems were pruned to a diameter of 2.5 cm., new growth consisted mainly of branches. An approximately equal number of branches and chupons were obtained as a result of pruning to 5-cm. diameter and more chupons than branches were observed after pruning back to 10-cm. diameter. Thus, when trees are pruned to obtain vegetative shoots for propagation, a good supply of fan branches can be obtained by cutting back to 2.5 cm. If chupons are required, the stems should be pruned back to a greater diameter.

5. Spraying

Specific instances where chemical control of disease has been successful are mentioned in Chapter IV. In general, spraying with insecticides appears to be uneconomical and wasteful. The problem of obtaining an adequate supply of water during the dry season must also be taken into account. To control fungus diseases, spray would have to be applied during the wet season, when most of the chemical might be wasted.[67]

Nicotine sulphate has been found to be successful against capsids, but frequent application is necessary, because it has no residual toxicity. The toxicity of DDT (aa'-bis parachlorophenyl $\beta\beta\beta$-trichloroethane) to capsid nymphs lasts for five months. Kerosene is an unsuitable solvent for use on cacao. A 2.5% emulsion of the insecticide in coconut oil, with soap as emulsifier is satisfactory.[68] Treatment with Gammexane (γ-benzene hexachloride) is limited by the difficulty of finding a solvent other than kerosene.

A recently evolved method for the dispersal of insecticides is by means of smoke bombs, but their effectiveness depends on the weather. Fog generators producing very fine droplets may prove to be effective. Close or irregular spacing of trees and ground conditions during wet weather militate against the use of ground machines. There is promise of success by dispersal of chemicals from helicopters, but it remains to be seen whether the additional cost will be repaid by improved yield.

[66] L. Murga, review of thesis by L. R. Holdridge, *Cacao Information Bull., 2,* No. 1, 5 (1950).

[67] H. R. Briton-Jones, *The Diseases and Curing of Cacao.* Macmillan, London, 1934.

[68] J. Nicol, in *Cocoa Conference 1948.* The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1948.

6. Selection for Breeding

The aim of selection is to find the most productive and hardy trees, as well as those giving the best flavoured beans.

Yield is governed by the size of tree, number of pods produced in a given period and quantity of dry cacao per pod.

West[69] has described the method of selection for productivity in Nigeria. In 1912, red and yellow pod Amelonado trees were planted. Yellow pod trees proved more productive and the red pod trees were rejected. All the yellow pod trees which failed to yield an average of 70 pods per annum over the ten years 1921–22 to 1930–31 or 90 pods for the five years 1925–26 to 1930–31 were eliminated. The number of pods required to produce 1 lb. of dry cacao was also considered. Forty-nine selections were made and the most outstanding one for yield also produced the largest beans (155 wet beans per lb.) as against the average of 171 for Nigerian cacao.

Progenies of Trinidad introductions averaged 150 wet beans per pound. The best (101 wet beans per lb.) has proved self-incompatible. Clonal progenies of Trinidad introductions averaged 143 wet beans per lb. in their first year of bearing. The trials contain selfed and crossed seedlings from the best local and introduced cacao.

Selections in Trinidad[70] are based on a minimum of 60 pods per annum per 144 sq. feet of area occupied and an average weight of 160 grams of wet cacao per pod. Trees giving wet beans averaging less than 4 grams in weight are rejected and selections exhibiting pollen incompatibility are discarded. The next step is to study the performance of clones from the parent trees of remaining selections from the standpoint of response to different types of soil, spacing, earliness of bearing and susceptibility to disease.

At the West African Cacao Research Institute, very little improvement has been recorded for local Amelonado selections. Amelonado is a poor yielder and very exacting in soil and environmental requirements. The performance of local Trinitarios is encouraging for self-fertilised progeny. The best introductions are from the Upper Amazon. A type from Costa Rica also shows marked superiority in the field. New types from the Gold Coast and Nigeria are being

[69] J. West in *Report and Proceedings of the Cocoa Research Conference 1945*. Colonial No. 192, His Majesty's Stationery Office, London, 1945.

[70] F. J. Pound in *Report and Proceedings of the Cocoa Research Conference 1945*. Colonial No. 192, His Majesty's Stationery Office, London, 1945.

multiplied at Tafo, Gold Coast, because the climatic conditions there are more favourable than in Nigeria. Controlled breeding for elimination of undesirable and increasing desirable characteristics has not yet been started.[71]

For quality, selections from clonal plots are made on bean size, colour, yield and self-compatibility.[72] Self-fertilised progenies and progenies of crosses between introductions from Trinidad, Ceylon and the Cameroons and Nigerian cacao are now under trial in West Africa. Selections for flavour can only be determined in conjunction with factory trials and are complicated by the fact that the manufacturer relies on a blend of choice and ordinary cacao for flavour development.

In Ecuador, 300 selections are under observation for resistance to witches' brooms disease, annual yield of dry cacao, number of pods to give 1 lb. of dry beans, percentage of diseased pods, age of tree, ease of rooting or budding, early vigour and growth rate, adaptability to different environments and earliness of bearing. Selections for resistance to witches' broom were made in the dry season after infected shoots had dried, and for pod rot during the wet season when the highest incidence occurs.[73]

A similar scheme for selection has been outlined by Bowman.[74] Trees selected should bear at least 75 pods, giving annual yield of 15 lb. of dry cacao in areas of two harvests, and preferably show no evidence of pod rot, but in heavily infected areas trees with not more than three infected pods may possess considerable resistance. For flavour tests, the beans should be cured by a standard method.

[71] O. J. Voelcker, *W.A.C.R.I. 1944–49*. West African Cacao Research Institute, Tafo, Gold Coast, undated.
[72] J. West in *Report and Proceedings of the Cocoa Research Conference 1945*. Colonial No. 192, His Majesty's Stationery Office, London, 1945.
[73] R. L. Fowler, *Cacao Information Bull., 1,* No. 21, 1 (1949).
[74] G. F. Bowman, *Cacao Information Bull., 1,* No. 20, 1 (1949).

CHAPTER IV

DISEASES AND PESTS OF CACAO

On the subject of disease, Martin-Leake[1] writes:

"The accumulation of a vast number of plants of the same species, varieties or even races and clones, in a compact area is a thing unknown in Nature and offers a promising field for the rapid development of those organisms to which the plant acts as host. The development is commonly termed disease. . . .

"Neither man nor the organism causing the disease is impartial and unbiased: Nature alone balances the scales and disease is her weapon of adjustment."

Referring to countries with a long-established agriculture, he declares that the danger lies in the introduction of an exotic organism which may assume epidemic form when freed from the control exercised in its natural habitat.

Ample confirmation of Martin-Leake's statements is provided by the magnitude of the ever-mounting losses of cacao trees through disease. Cacao is not native to those countries where the major part of the world crop is produced. Not only has it suffered from intensified attacks by the insects and organisms which were its original enemies, but it has also become an alternative host for parasites indigenous to the countries where it has been introduced.

Cacao is susceptible to attack by many varieties of fungus. In certain instances their entry is made by way of punctures in the tissue caused by insects. Death of the tree may also result from onslaughts by insects, without the intervention of fungus infection. In recent years, losses due to virus diseases, conveyed by insect vectors, have assumed formidable proportions. In view of their importance, virus diseases will be considered first.

[1] H. Martin-Leake, *Internat. Sugar J., 49,* 174 (1947).

1. Virus Diseases

A. THE NATURE OF PLANT VIRUSES

Viruses are defined by Bawden[2] as obligately parasitic pathogens, too small to be resolved by microscopes using visible light. Information concerning their shape and structure has been obtained by means of the electron microscope. As some viruses can be isolated in crystalline form, it is possible to determine their size by X-ray diffraction analysis which has revealed that the dimensions of the smallest viruses are not much greater than molecular size.

Viruses resemble living organisms in their ability to multiply, but they are incapable of independent existence in cell-free media.[3] Those examined in the purified state occur as nucleoproteins and they only develop and become infective when placed in a substrate containing the enzyme systems necessary for their multiplication. Viruses are usually transmitted from one plant to another by sucking insects whose power of retention of infectivity varies according to species. After multiplication at the site of attack, the virus passes to the phloem and travels to distant parts of the host. It is borne away from tissue engaged in photosynthesis by the translocation stream and travels towards the regions of active growth. The signs of infection appear first on newly developed leaves. Viruses are the cause of internal changes, such as reduction ot chloroplasts or necrosis of phloem.[4]

B. SWOLLEN SHOOT DISEASE

By far the most devastating damage of cacao trees is attributable to swollen shoot disease, first recorded in the Gold Coast. It was then correctly diagnosed as a virus disease. Later on, opinion swayed towards the belief that the symptoms were caused by soil deterioration. Control measures, which might then have arrested its spread, were unfortunately abandoned until further investigations confirmed that viruses were, in fact, responsible for the disease.

At least twenty swollen shoot viruses, some comparatively inild and others virulent, have been identified.

The disease takes its name from the characteristic swellings seen at one or more places on cacao shoots or branches, although this

[2] F. C. Bawden, *Nature, 155,* 156 (1945).
[3] K. M. Smith, *Endeavour, 4, 22* (1945).
[4] F. C. Bawden, *Nature, 155,* 156 (1945).

particular symptom is not exhibited by all infected trees. In the early stages of the disease, twig swellings are not easily discovered on mature trees and only become apparent about a year after the tree has been infected.

The first symptoms are seen on the leaves.[5] On young leaves, red lines appear along the sides of the veins. The red colour disappears as the leaves turn green. On more mature leaves, small yellow spots or streaks may be distributed over the entire surface, or larger spots or lines occur beside the main veins. These symptoms are more permanent and are still discernible when the leaf is old. In addition, crinkling and leaf tip necrosis may occur. Leaf symptoms are followed by twig swellings. The pods are smaller and more spherical than those of healthy trees. Immature pods are mottled with darker green or large red spots immediately before ripening, but this condition disappears when the pods ripen.

As the disease progresses, the older leaves fall prematurely and the tree is unable to replace them with young leaves. In time, the tree is almost leafless and the upper branches are dead. A more malignant strain known as A will bring about the death of the tree six to nine months after infection. Sub-lethal strains B and C work more slowly and the dying process takes two or three years.[6] Other strains are comparatively innocuous, but they may possibly mutate into lethal or sub-lethal strains.

Swollen shoot disease in one or other of these strains is found in all parts of the Gold Coast. In its most malignant form it has caused great havoc in the Eastern Province and to a much smaller degree in Ashanti and the Western Province. It occurs in a milder form in Nigeria and the Ivory Coast. Older trees are more prone to virus attack.

The insect vestors are species of mealybugs, so called on account of the waxy material with which the adults cover themselves. It is probable that the insects are indigenous to West Africa and that they remained unnoticed because they existed on alternative hosts without causing very obvious harm.

By means of their body wax, mealybugs attach themselves to the stems and pods of cacao and suck the juice. The young are capable of

[5] *Swollen Shoot of Cacao*. Memorandum by West African Cacao Research Institute, Tafo, Gold Coast, March 1945.
[6] H. Tempany, *Confec. Production, 13,* 13 (1947).

slow movement and travel from one tree to the next when the foliage is in contact. They are also windborne for some distance or carried by attendant ants which build protective tents over the mealybug colonies.

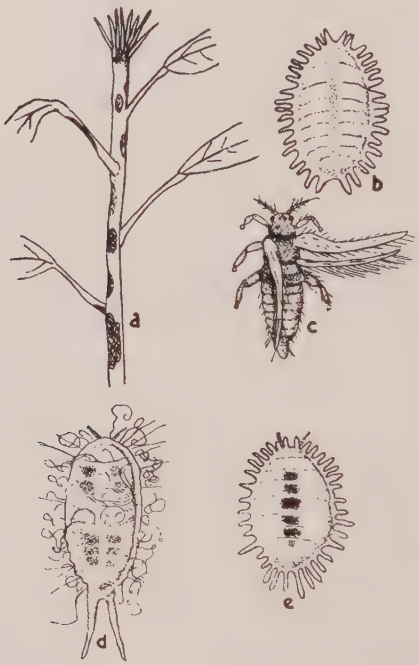


Fig. 11. (a) Cacao twig showing damage by *Sahlbergella singularis.* (b) *Pseudococcus citri,* Risso, adult. (c) *Selenothrips rubrocinctus,* Giard, adult. (d) *Ferrisia virgata,* Ckll., adult. (e) *Pseudococcus njalensis,* Laing, adult. (By courtesy of J. Nicol.)[7]

In the Gold Coast, the commonest vector of swollen shoot disease is *Pseudococcus njalensis,* Laing (Fig. 11e). It conceals itself in cracks in the bark in the region of leaf canopy, but is also to be found in pods. As many as 2000 mealybugs may be feeding at the same time on one cacao tree,[7] although a much smaller number is more usual.

[7] J. Nicol, *The Insect Pests of Cacao Trees.* West African Cacao Research Institute, Tafo, Gold Coast, 1948 (typescript).

The adult is pale pink and measures 2 mm. by 1.8 mm. It possesses 18 pairs of waxy filaments. The female lays 30 to 40 minute pink eggs. They hatch almost immediately and the larvae crawl about for a short while before commencing to feed. Three skins are shed in the 20 to 25 days before the adult emerges. During the larval period, the insect is mobile and may travel to another tree. The adult lives 15 to 30 days before oviposition. The males do not feed and live for only a few hours or at most for two days.[8]

Ps. njalensis is capable of transmitting all the strains for which it has been tested. Using seeds as test plants, Posnette[9] observed that symptoms of swollen shoot disease appear on the first or second flush of leaves developed after germination, when transmission has occurred.

The insects are not heavily parasitised. Natural parasitism in the Gold Coast occurs to the extent of about 3% in adults. Posnette and Strickland[10] investigated the effect of parasites introduced from Kenya where they control the mealybug of coffee, *Pseudococcus kenyae*. The parasite tested was *Anagyrus* sp. near *kivuensis* and it has proved successful in parasitising *Pseudococcus njalensis*.

Pseudococcus citri, Risso (see Fig. 11b), is a pale yellow, oval shaped insect measuring 2.8 mm. by 2.0 mm. when in the adult stage. Like *Pseudococcus njalensis,* it has 18 pairs of waxy filaments. It is to be found on young shoots and also on pods. Except that hatching does not occur until some days after oviposition, its life-history is similar to that of *Pseudococcus njalensis*. It is an effective vector for strain A. Feeding experiments have demonstrated that the virus is taken up after less than four hours' feeding on an infected plant and that it can be transmitted to a healthy plant in less than three hours' feeding time.[11]

Ferrisia virgata, Ckll. (Fig. 11d), is occasionally found on cacao. The adult is dark blue or grey and measures 4 mm. by 2 mm. It has but one pair of filaments, situated at the rear end. The eggs

[8] O. J. Voelcker, *Ann. Rept. West African Cacao Research Institute, 1946–47* (1948).
[9] A. F. Posnette, *Nature, 159,* 500 (1947).
[10] A. F. Posnette and A. H. Strickland, *Nature, 163,* 105 (1949).
[11] O. J. Voelcker, *Ann. Rept. West African Cacao Research Institute, 1946–47* (1948).

hatch out 24 hours after laying. The larvae are windborne. No attendant ants have been identified with certainty.[12]

During the mobile stages of their life cycle, mealybugs can pick up the virus from any part of an infected living tree within a few hours of feeding and they can transmit it to a healthy tree at any time within 36 hours of feeding.[13]

No cacao tree immune to virus has yet been discovered, though there is evidence that varying degrees of tolerance can occur.[14]

A laboratory test for the presence of swollen shoot virus (strain 1A) which can be applied to cacao stems kept under moist conditions for three weeks, but is not recommended for field work, has been devised by Hancock.[15] Transverse sections of diseased stems, when immersed in anhydrous methanol containing two or three drops of hydrochloric acid per 100 ml. rapidly develop a magenta colour in the wood. Virus-free shoots also become coloured, but much more slowly. Colour formation appears to be due to condensation of furfural with phloroglucinol, under the influence of the acid methanol. One stage of the reaction is catalysed by the virus.

There is little doubt that swollen shoot virus must have spread to cacao from wild plants indigenous to West Africa. No alternative hosts have been found outside the families *Bombacaceae* and *Sterculiaceae*. Owing to the lack of visible evidence, transmission tests have been used to obtain proof of infection. Seven species indigenous to West Africa have been shown to be infectible by a technique described by Posnette.[16] Mealybugs holding the virus were allowed to feed on the cotyledons of cacao beans. When the second pair of leaves were unfolding, insects feeding on them were transferred with a brush to young seedlings of other species. After 24 hours' feeding, the mealybugs were killed with a nicotine spray. About a month later, virus-free mealybugs, taken from healthy cacao, were allowed to feed on seedlings of the other species. The insects or their progeny were then transferred to healthy cacao beans and allowed to feed for 24 hours.

[12] J. Nicol, *The Insect Pests of Cacao Trees*. West African Cacao Research Institute, Tafo, Gold Coast, 1948 (typescript).
[13] O. J. Voelcker, *W.A.C.R.I. 1944–49*. 3. West African Cacao Research Institute, Tafo, Gold Coast, undated (typescript).
[14] O. J. Voelcker, *Ann. Rept. West African Cacao Research Institute 1946–47* (1948).
[15] B. L. Hancock, *Trop. Agr. (Trinidad), 26*, 54 (1949); *C.A., 44*, 708 (1950).
[16] A. F. Posnette, *Cocoa Conference 1949*. (Alternative Hosts of Cacao Viruses.) The Cocoa, Chocolate and Confectionery Alliance Ltd., London 1949.

If the beans germinated into infected cacao seedlings, the wild plants on which the insects had previously fed must have been infected.

In the *Bombacaceae, Bombax buonopozense* (kapok), *Ceiba pentandra* (silk cotton) and *Adansonia digitata* (baobob tree) can be infected and in the *Sterculiaceae, Sterculia tragancantha, Sterculia rhinopetala, Erythropsis barteri* and *Cola cordifolia* are capable of harbouring one or other of the swollen shoot viruses. No swollen shoot viruses have as yet been found in commercial kolas.

The viruses in the Western Province of the Gold Coast are different from those in the Eastern Province and most of those identified in Nigeria are not found in the Gold Coast. The selectivity of wild hosts suggests that wild plants are responsible for new outbreaks.

The West African cacao crop is threatened with extinction unless effective control measures are applied. In the Gold Coast, control by chemical sprays is out of the question, except for young cacao trees, because the trees are irregularly distributed amongst other vegetation, and many of the farms have no access to a road. Even where the trees are planted in orderly rows, spacing is too close to permit spraying from trucks. Mealybugs are difficult to destroy because they are concentrated in the canopy layer and their protective tents form a barrier to the proportion of spray reaching their colonies.

Insect parasitism accounts for only a small percentage of the virus vectors.[17] A new form of biological control, which has yielded promising results in the laboratory, is to parasitise the mealybugs with *Aspergillus parasiticus*, Speare. Nicol, Owen and Strickland[18] have reported a 90–96% kill by treatment with a mixture of talc dust and spores of the mould.

Although mild strains of viruses have been found[18a] which give virtually complete protection against virulent strains, their eventual effect on vigour and yield has yet to be determined.

Breeding of resistant varieties is a long-term proposition. By comparison with new introductions, Amelonado cacao, which is extensively grown in West Africa, offers very little resistance to disease.

The only effective method of control is by cutting out the diseased trees. Because symptoms are not easily recognised in mature cacao in the earlier stages of the disease, the apparently healthy trees

[17] A. F. Posnette and A. H. Strickland, *Nature, 163,* 105 (1949).
[18] J. Nicol, H. Owen and A. H. Strickland, *Nature, 165,* 490 (1950).
[18a] A. F. Posnette and J. McA. Todd, *Ann. Appl. Biol., 38,* 785 (1951).

surrounding the diseased trees must also be removed as a precautionary measure. Where possible, alternative hosts should also be removed. Eradication of such tall trees as *Cola cordifolia* and *Ceiba pentandra* involves heavy labour as well as the danger caused by scattering of the insect population during felling. Removal of their seedlings and saplings will contribute to the control of the disease on sites where it is impracticable to fell the mature trees.

Posnette[19] recommends spraying with nicotine sulphate (1:1500) before and during the felling of cacao trees, including a perimeter of 20 yards around the outbreak, to restrict the spread of disease by scattering of insect vectors.

Unfortunately, it has been difficult to persuade the West African farmer that the policy of eradication of diseased trees is the only hope of saving him from eventual bankruptcy. In the Gold Coast, opposition to compulsory felling led to civil commotion in 1947. The campaign of compulsion was therefore temporarily abandoned, with disastrous effects on the crop, as noted on p. 267.

As a result of the findings of a Commission of Enquiry,[20] propaganda has been intensified. The farmers now receive a bonus for rehabilitation as well as compensation for trees felled. The Commission recommended that the Eastern Province be re-established on a modern basis, in larger units than the present three-acre farms, after allowing the land to lie fallow for two to three years. Resistant types of trees will then be planted at sufficient distance to permit spraying.

In the Ivory Coast, where swollen shoot has affected cacao in several districts, control measures were in abeyance during the war years. It has been estimated that 1,500,000 trees should be destroyed, chiefly in the Abengourou district, where 2000 acres are infected. Measures were begun in 1946. Up to 1947, 160,000 trees had been eradicated.[21]

The latest approach to the control of mealybug vectors is by the application of a systemic insecticide to the roots of all cacao trees surrounding a focus of infection. In this way it is hoped that the spread of infection may be arrested with less sacrifice, as only those

[19] A. F. Posnette, *Trop. Agr. (Trinidad), 20,* 116 (1943).

[20] *Report of Commission of Enquiry into Swollen Shoot Disease in the Gold Coast.* Colonial No. 236, Colonial Office, London, 1949; G. Evans, *Nature, 163,* 271 (1949).

[21] A. Balleyguier, in *Cocoa Conference 1949.* The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1949.

trees which subsequently show infection would then have to be cut out.

In 1951, a large-scale experiment was launched by treatment of the soil round the roots of 500 infested trees in the Gold Coast with "Hanane" (a mixture of bis-dimethylaminofluorophosphine and bis-dimethylaminophosphonous anhydride). Six weeks later, the mealybug population had been reduced by 99.9%. Re-treatment of separate plots of 100 trees at intervals of 8 and 12 weeks showed that the number of mealybugs was kept at low level by the three treatments.

The number of flowers set per tree indicated that soil treatment was not detrimental to pollinating insects. Parasites and predators did not suffer apart from the fact that there were insufficient mealybugs to sustain them.

Apart from the cost of this form of control, it is more likely to be acceptable to the cultivator than wholesale cutting out.[21a]

C. RED MOTTLE VIRUS

This disease is confined to the Western and Northern slopes of the Northern Range in Trinidad and is diagnosed by the presence of red pigment along the side of the main veins of young leaves. As with swollen shoot disease, the markings fade as the young leaves become green, but are still discernible as faint shadows. Leaf crinkling and tip scorch occur and the pods become mottled, but no swellings are seen on branches. The rate of spread of the disease is rapid.[22] The chief vectors are *Ferrisia virgata, Pseudococcus citri* and *Pseudococcus brevipipes.* Symptoms usually appear within 25 to 44 days after infection.

Baker and Dale[23] have made further observations on the disease. Two strains have been distinguished. Red mottle is caused by strain A. The lowest produced leaf of a new shoot is the most likely place to find it. Red blotches are seen on young pods of yellow-podded trees. Strain A can cause dieback and reduction of yield. Strain B causes vein-clearing, which persists after leaf hardening. Leaf symptoms are more striking in strain B. The effect on condition and yield has not been assessed.

[21a] A. D. Hanna, W. Heatherington and E. Judenko, *Nature, 169,* 334 (1952).
[22] A. F. Posnette, *Trop. Agr. (Trinidad), 21,* 105 (1944).
[23] R. E. D. Baker and W. T. Dale, *Trop. Agr. (Trinidad), 24,* 127 (1947).

2. Damage Caused by Capsid Bugs

Capsids can cause considerable damage in relation to their comparatively small numbers.

In the Gold Coast and Nigeria they are not very numerous between March and August; in September their population increases rapidly and there is a sudden decline at the end of the dry season.[24]

Injury to young cacao shoots by capsid lesions may result in the death of the stem through toxin injected at the time of feeding (Fig. 11a). In the case of hardened stems, the toxin may produce a wound which heals in a few days. When the wound is infected with fungus, more serious damage and even death of the tree may occur. Some capsids, e.g., *Helopeltis,* confine their feeding mainly to pods.

In West Africa, two capsids, *Sahlbergella singularis,* Hagl. and *Distantiella theobroma,* Dist., cause great damage in association with the fungus *Calonectria rigidiuscula* (Berk et Brme.) Sac.

The adult *Sahlbergella singularis* is a speckly brown insect about half an inch long, is fully winged and can fly. It is found throughout the cacao-growing countries of West Africa. The silk cotton tree (used for shading cacao) is an alternative host.

Distantiella theobroma (formerly known as *S. theobroma*) is considerably darker in colour than *Sahlbergella singularis.* It is found on silk cotton and citrus trees as well as on cacao.

The life-histories of *Sahlbergella singularis* and *Distantiella theobroma* are similar.[25,26] The small white eggs laid in the tissues of twigs, pods or pod stalks, carry two filaments which project outside the plant tissue and enable the egg to breathe. The incubation period is from 12 to 18 days and the nymphal life of five instars averages 23 days. Oviposition commences five to ten days after the adult female emerges and 150 eggs may be laid over a period of 46 days. The capsid population is relatively small, but a few *Distantiella theobroma* nymphs can cause great damage. The insects feed at night by puncturing the tissues and sucking the sap. Simultaneously a toxin is injected. Primary damage is due to collapse of the tissues around

[24] O. J. Voelcker, *W.A.C.R.I. 1944–49.* West African Cacao Research Institute, Tafo, Gold Coast, undated (typescript).

[25] O. J. Voelcker, *Ann. Rept. West African Cacao Research Institute, 1946–47* (1948).

[26] J. Nicol, *The Insect Pests of Cacao Trees.* West African Cacao Research Institute, Tafo, Gold Coast, 1948 (typescript).

the punctures. The sheltering places of the insects are in leaf axils, at stem junctions or under pods. If the punctures on a shoot are numerous, the leaves become brown and wrinkled and the shoot dies. Similarly, a heavily attacked pod may die. Sucker growth is suitable for oviposition and feeding, and capsids are to be seen there especially after the pods have been harvested.

Distantiella theobroma is more commonly found on young cacao and is capable of causing death by destruction of successive leaf flushes. Dieback and death of older trees is usually due to fungal infection of the punctured tissues.

Damage in uninfected tissues occurs mainly in the medullary rays of the cortex and only to a limited extent in the medullary rays of xylem. The medullary rays of the cambium are also destroyed, but there is negligible damage to the phloem or phloem cambium. The wound is healed by formation of wound cambium from cortical medullary ray tissue. There is no cankering of healed lesions and no evidence of bark roughening.

Capsids of the genus *Monalonion* cause considerable damage in Peru, Ecuador, Colombia and Central America.

When capsid wounds are infected by fungus, the damage spreads and after about two weeks there is extensive discoloration in the phloem. *Calonectria* mycelium infiltration is intracellular and therefore xylem damage is usually confined to the medullary rays. The lesion heals by the growth of callus tissue and is distinguished by deep-seated canker, extending to and discoloring the xylem. Evidence points to the association of roughened bark with fungal infection.[27]

Perennial damage by capsids causes the formation of capsid pockets and results in the stunting and death of branches. In extreme cases, even the trunk may be killed.

When trees have been weakened by drought or repeated capsid attack, the spread of *C. rigidiuscula* may result in rapid dieback.

Three distinct types of spores are formed. The microconidia occur on the mycelium and the macroconidia are borne on small pinkish sporodochia emerging through the bark of recently killed stems. These two stages have been described as *Fusarium decemcellu-*

[27] O. J. Voelcker, *Ann. Rept. West African Cacao Research Institute, 1945–46* (1947).

lare. The perithecia are borne in groups on small stromata and are seen on stems that have been dead for some time.[28]

C. rigidiuscula damage is often difficult to isolate from that of *Botryodiplodia theobromae*, Pat. which is a secondary infection following closely on incipient dieback.

Control measures are being sought to destroy both insects and fungi.

A simple method which has proved effective in reducing capsid attacks on young cacao plants up to five feet in height is by hand painting with DDT emulsion—(see Chapter III, Spraying)—at points on the stem where the insects are likely to feed or rest.[29]

Distantiella theobroma attacks on young plants can be chemically controlled by spraying with nicotine sulphate. *Sahlbergella singularis* populations are generally inaccessible as they are more commonly found on older trees. There is some hope of success by parasitism. *Sahlbergella singularis* is naturally parasitised in the nymphal stage by *Euphorus sahlbergellae*, Wilk., which is hyperparasitised by *Mesochorus melanothorax*, Wilk.[30] The degree of parasitism by *Euphorus sahlbergellae* is insufficient for active control. No parasites of *Distantiella theobroma* have yet been discovered. Predators destroy a proportion of nymphs, and ants of the genus *Macromischoides* protect cacao leaves by making mud nests on the lower surface.[31]

It is probable that water relationships and nutrient status of the soil affect the spread of *C. rigidiuscula*.

Helopeltis feeds on immature cacao pods. The damage can be distinguished from that of *Sahlbergella singularis* by the fact that punctures occur on all parts of the surface. In Ceylon and Java, *Helopeltis* is responsible for much damage to cacao. Two species, *H. theivora* and *H. antonii* are described by van Hall.[32] The former is greenish and the latter has a reddish or black thorax and the back

[28] O. J. Voelcker, *Ann. Rept. West African Cacao Research Institute, 1945–46* (1947).

[29] O. J. Voelcker, *W.A.C.R.I. 1944–49*. West African Cacao Research Institute, Tafo, Gold Coast, undated (typescript).

[30] O. J. Voelcker, *Ann. Rept. West African Cacao Research Institute, 1945–46* (1947).

[31] J. Nicol, *The Insect Pests of Cacao Trees*. West African Cacao Research Institute, Tafo, Gold Coast, 1948 (typescript).

[32] C. J. J. van Hall, *Cocoa*. Macmillan, London, 1914.

of the female is green. Nicol[33] describes the adult insects in West Africa as having slender yellowish bodies. He states that small pods when badly attacked do not mature. Damage to the larger pods is less serious unless followed by mould infection.

3. Thrips Damage

Selenothrips rubrocinctus, Giard (Fig. 11c), indigenous to tropical America, is now to be found in most cacao-producing countries and its presence assumes some importance in the West Indies, West Africa and Brazil.[34]

Thrips are especially common on unshaded cacao. The adult *Selenothrips rubrocinctus* is $^1/_{16}$ in. long and is almost black. It has four wings, fringed with bristles. The greater part of thrips damage is done by nymphs. Their bodies are yellow, banded with red. They live in colonies and while feeding on the sap, exude a fluid which leaves a black spot on pod or leaf. Leaves, when severely attacked, become yellowed and fall. Pod damage is confined to the skin which becomes browned through the formation of cork tissue, but the beans are unaffected. Severe infestation leads to heavy leaf fall, followed by production of new foliage. When this, in its turn is attacked, the leaves of the next flush are too feeble to support the life of developing fruits which then wither and fall off. Repeated attacks result in the death of the tree.

From records in the Gold Coast, Nicol[35] gives the incubation period as two days, nymphal life 10 days and total egg to adult life-cycle as 10 to 15 days.

Outbreaks can be dealt with by spraying with Bordeaux mixture or milk of lime or dusting with slaked lime. *Selenothrips rubrocinctus* is parasitised in the Gold Coast by *Dasycapus parvipennis,* Gahan. This parasite was introduced into Trinidad, in an attempt to reduce thrips attacks by biological control, but it has not been effective.[36] Thrips-resistant varieties of cacao are being sought. Immunity appears to be linked up with resistance to leaf puncturing. Laboratory

[33] J. Nicol, *The Insect Pests of Cacao Trees.* West African Cacao Research Institute, Tafo, Gold Coast, 1948 (typescript).
[34] E. McC. Callan, *Trop. Agr. (Trinidad), 20,* 127 (1943).
[35] J. Nicol, *The Insect Pests of Cacao Trees.* West African Cacao Research Institute, Tafo, Gold Coast, 1948 (typescript).
[36] E. McC. Callan, *Trop. Agr. (Trinidad), 20,* 127 (1943),

tests on food preference and obligatory food tests showed that a high-yielding commercial type of cacao, selection RT18, is unpalatable to thrips.[37]

4. Fungus Diseases

Briton-Jones[38] has described a number of fungal diseases of cacao. These comprise eight root diseases, four stem diseases and six diseases affecting pods, in addition to witches' broom disease which attacks both shoots and pods of cacao.

The penetration of roots is largely the result of inadequate soil drainage giving rise to conditions favourable for fungal growth. Severe attacks may cause death of the trees. While isolation by trenching does good, the surest way to check fungus development is by improvement of soil conditions. Briton-Jones recommends digging the drainage system before planting the crop, so that the young trees do not develop a shallow root system.

The root disease organisms mentioned by Briton-Jones are not confined to cacao. They are *Rigidiporus microporus* (Swartz) van Overeem, *Fomes noxius*, Corner (Brown root disease), *Sphaerostilbe repens*, B. et Br. (Red root disease), *Ganoderma pseudoferreum* (Wakef.) van Overeem et Steinmann (Wet rot), *Ustulina zonata*, (Lev.) Sacc. (Collar rot), *Armillaria mellea* (Vahl.) Fr. (Root rot or Collar crack) and *Rosellina*.

The steam disease organisms described are *Botryodiplodia theobromae*, Pat., associated with dieback and already referred to in connection with capsid attack, species of *Corticium* and *Marasmius* which cause thread-blights, *Corticium salmonicolor*, B. et Br., giving rise to "pink disease" and *Marasmius sarmentosus*, Berk., the organism responsible for horsehair disease.

Pod diseases due to fungal penetration are diplodia, caused by *Botryodiplodia theobromae*, Pat., mealy pod disease, associated with *Trachysphaeria fructigena*, Tab. et Bunt., black spot due to *Sphaeronema* sp., anhtracnose (*Colletotrichum spp.*), and the important pod rot diseases caused by *Phytopthora palmivora*, Butl. and *Monilia*.

[37] E. McC. Callan, *Trop. Agr.* (*Trinidad*), *20*, 127 (1943).
[38] H. R. Briton-Jones, *The Diseases and Curing of Cacao*. Macmillan, London, 1934.

Witches' broom disease, due to the organism *Marasmius perniciosus,* Stahel, is causing particular concern in Trinidad and the South American continent.

A. BLACK POD DISEASE

Phytopthora palmivora, Butl. occurs in every cacao-producing country and causes considerable damage to crops in wet weather, more especially to pods and pod cushions, though chupon attack may be appreciable in some countries. Briton-Jones states that the fungus can infect uninjured as well as wounded pods of all ages. Immature pods are generally infected either at the stalk end or the tip. A brown discoloration around the site of attack rapidly extends over the entire surface and the pod may later become black or be whitened by filaments of other moulds. The beans of young pods are likely to be destroyed by invading mycelia. In older pods the beans may survive. When they are dried without sweating, they are marketed as "black cacao." Dead beans from pods killed by the disease contain more fat, on the dry weight, than beans from healthy pods grown on the same tree. Free fatty acid is not affected.[39]

Tissues become infected by the penetration of the germ tubes through stomata or epidermis. The mycelia may traverse the pod stalk and invade the branch or trunk, causing a canker. When the limb is encircled by canker it will die. Chupon wilt is also caused by *Phytopthora palmivora.*

Spraying with fungicides significantly reduces pod diseases. Bordeaux mixture has proved more effective than "Perenox" and nicotine sulphate.[40] In Costa Rica, it has been found profitable to spray into the canopy. Chupon wilt is not appreciable in the Gold Coast, where the main sites of infection are pods and cushions, therefore spraying is directed at the pods. In Nigeria, it was found that black pod disease could be controlled without recourse to spraying or dusting, by removal of all infected pods during the critical period between June and August.[41] When the price for the "light" crop was unremunerative during 1943 and 1944, the farmers neglected this

[39] J. West, *Report and Proceedings of the Cocoa Research Conference, 1945.* Colonial No. 192, His Majesty's Stationery Office, London, 1945.
[40] *18th Quart. Rept. West African Cacao Research Institute,* Oct.--Dec. 1948.
[41] J. West, *11th Ann. Bull. Dept. Agr., Nigeria.* 1936.

precaution. The result was an alarming increase in black pod disease. The loss in Nigeria approaches 10,000 tons annually.[42]

Black pod is a major disease in the Cameroons. Its spread can be checked by avoiding sites where mists predominate either during rains or at elevations of over two thousand feet. Wider spacing favours pod infection, because it induces low branching and high humidity within the leaf canopy. Closely planted trees produce tall trunks with a high canopy and most of the pods are borne on the trunks under satisfactory conditions of air circulation. *Phytopthora palmivora* spreads rapidly when young pods showing brown lesions of the fungus in its actively sporulating stage are allowed to remain on the tree.[43]

B. MONILIA POD ROT

Invasion of pods by *Monilia* accounts for much damage to crops in Ecuador. It occurs also in parts of Colombia, Venezuela and Peru. Pods are most liable to be infected when they are 8 to 10 cm. long. Deformation and discoloration are caused and the tissues within the husk become watery and the seeds are quite useless.

Monilia flourishes under humid conditions. Its control is assisted by closer planting and spraying with Bordeaux mixture.

C. WITCHES' BROOM DISEASE

This disease was first reported in Surinam in 1895. By 1926, the cacao industry of that country was reduced to almost negligible proportions. It is prevalent in South America and at the present time is inflicting severe losses on crops in Trinidad and Tobago.

Stahel established that the disease was caused by a species of *Marasmius*, now known as *Marasmius perniciosus*, Stahel.[44] The common name witches' broom was given to the disease on account of the appearance of the infected shoot. It becomes much thickened at the base, due to hypertrophy of cortical tissues. The leaves are usually dwarfed and the axil buds produce short shoots bending downwards or outwards. According to Stahel's description of the fungus, the fructifications (mushrooms) are spherical. The cap, between 5 and 15 mm. long, is faintly pink on the upper surface. A dark red central

[42] O. J. Voelcker, in *Report and Proceedings of the Cocoa Research Conference, 1945*. Colonial No. 192. His Majesty's Stationery Office, London, 1945.
[43] J. West, in *Cocoa Conference 1948*. The Cocoa, Chocolate and Confectionery Alliance, London, 1948.
[44] G. Stahel, *Dept. van den Landbouw in Suriname, Bul. 33*, Sept. 1925.

spot is surrounded by about fifteen red rays. The fructifications are supported on white or pale yellow stalks. The spores are white. They germinate in wet weather.

Witches' broom attacks all the living tissues of the cacao plant, particularly young shoots.[45] Baker and Dale studied the progress of the disease on infected trees in Trinidad, by counting the number of fan, chupon and cushion brooms formed annually.[46] Between 1934 and 1940, the mean number of brooms per tree was 51. In the season 1940–41, an average of 162 brooms was recorded; during the following season, they averaged 205 and for the part of the following year over which observations were made, there were 336 brooms per tree, of which 237 were fan and chupon brooms. Up to 1943, bearing was comparatively unimpaired. A possible explanation is that fan brooms have sufficient leaves and chlorophyll, and might be self-supporting except for mineral nutrient supply.

Different modes of pod infection are described by Dale.[47] Pods are indirectly attacked through systematic infection when growing on diseased cushions. There is no trace of developing ovules. Pods become strawberry-shaped, due to hypertrophy of the cortex and are generally less than 6 cm. long. Infected pods become dark brown and dry out. The hollow centre is penetrated by mycelia. Infection is also caused through penetration by germ tubes via the stomata, when the pod is only 1 cm. long. Development is arrested but the pod may be 12 cm. to 15 cm. long before becoming necrotic. A period of 80 or 90 days may elapse between the time of infection and development of necrotic symptoms. The husk is often very hard and at first contains a clear liquid. Pods distorted by shell hypertrophy do not ripen normally. The infected area hardens and becomes dark brown or black and the beans are destroyed.

Larger pods show few signs of infection until they are ripening, when the husk becomes dark and woody and the beans throughout the pod are attacked. Sometimes, in a locally infected pod, some of the beans remain whole. When penetration is confined to the rind, only those beans in contact with it are damaged. Unless such pods are harvested immediately they are ripe, all the beans inside will suffer.

[45] F. J. Pound, *Bull. Officiel de l'Office Internat. du Cacao et du Chocolat, 10,* 91 (1940).
[46] R. E. D. Baker and W. T. Dale, *Trop. Agr. (Trinidad), 21,* 170 (1944).
[47] W. T. Dale, *Trop. Agr. (Trinidad), 23,* 217 (1946).

There may be no obvious external symptoms of infection. In such instances the inner layer of the husk shows browning and only slight bean damage occurs. Other pod rots such as *Colletotrichum*, *Botryodiplodia theobromae* and *Phytopthora palmivora* sometimes mask *Marasmius* attack.

According to observations by Dale,[48] the sporophore or mushroom of *Marasmius* deposits spores when the temperature falls to 80°F. This happens at 6 p.m. and by 10 p.m. there is an adequate supply of spores. They germinate two hours after deposition.

Marasmius can only be spread by spores which develop on *dry* brooms. Spores are never produced on green brooms and they occur on dry ones after a period of dormancy. Brooms dry out five or six weeks after their formation or at most after ten weeks. There is then a dormancy period of from five to six months without sporophore formation and the disease may be checked to some extent by removal of brooms during this period.[49] When sporophore production commences, it continues, except for a lull during the dry season, so long as the broom is allowed to remain on the tree. The hope that routine removal of brooms during the dormancy period might assist in lowering the incidence of the disease was fulfilled during the first season of trial, but in the following year, negative results were obtained.[50]

Chemical control by spraying or dusting is not feasible and the one real hope of overcoming the disease lies in the development of resistant types. Closer plating tends to reduce the number of infected pods.[51]

5. Minor Diseases and Pests

Briton-Jones describes an algal disease, known as red rust disease, caused by *Cephaleuros mycoides*, Karst, which attacks tea, coffee and cacao.[52] The alga occurs saprophytically in red patches on the upper surface of leaves and also attacks twigs. It can be controlled by removal of affected twigs, application of Bordeaux mixture and increase of overhead shade.

[48] W. T. Dale, *Trop. Agr. (Trinidad), 23,* 217 (1946).
[49] Editorial, *Trop. Agr. (Trinidad), 21,* 21 (1944).
[50] C. A. Thorold, *Trop. Agr. (Trinidad), 20,* 176 (1943).
[51] R. E. D. Baker and W. T. Dale, *Trop. Agr. (Trinidad), 21,* 198 (1944).
[52] H. R. Briton-Jones, *The Diseases and Curing of Cacao.* Macmillan, London, 1934.

Sickle disease occurs in West Africa and is due to the balance of soil nutrients being upset through excess of potassium derived from heaps of rotting pod husks left behind after the beans have been collected for fermentation.[53] The name originates from the shape of deformed leaf which becomes curved. Another symptom is leaf-mosaic and, on this account, the attack is sometimes mistaken for swollen shoot disease.

Leaf-cutting ants, *Atta cephalotes,* L. and *Accromyrmex subterraneus,* For., var. *bruneus,* For. cause damage to cacao trees in Bahia. The former erects a nest, about three feet high, in contact with cacao trees and the latter removes young shoots, cherelles and epidermis of pods to make a nest which is often built around a cacao tree. *Azteca paraensis,* For., var. *nociva,* Borg. causes damage to cacao through cutting young shoots to obtain sap for nest-building, thus leaving the ends of shoots denuded of leaves and broomlike in appearance.[54]

The "cacao-pod borer," *Charcoma strictograpta,* Harp., is a small, grey, spotted moth which moves by night and lays its eggs near the stalk end of pods. The caterpillar, on hatching, proceeds to bore its way through the husk, leaving frass (excreta and other refuse) adhering to the pod.[55]

Earias biplaga, Wilk. is a green moth. It oviposits on leaf buds and the caterpillar feeds on young cacao leaves.[56]

Mallodon downesii, Hope, a dark brown beetle more than 2.5 inches long, known as the cacao stem borer, is found in West Africa. Boring is done by the larva, which causes damage to stems. *Tragocephala gorilla,* Thomp. and *Tragocephala chloris,* Chev. are black beetles banded with yellow or orange. Their larvae bore inside the stems of young cacao trees.[57]

The tobacco beetle, *Lasioderma serricorne* is able to attack sound dry beans. Damage to cacao by this insect appears to be on the increase in warehouses in Nigeria. Control by DDT sprays is recommended. The cocoa weevil *Araecerus fasiculatus* will not attack beans

[53] *Swollen Shoot of Cacao.* Memorandum by West African Cacao Research Institute, Tafo, Gold Coast, March 1945.
[54] P. Silva, *Trop. Agr. (Trinidad), 21,* 8 (1944).
[55] J. Nicol, *The Insect Pests of Cacao Trees.* West African Cacao Research Institute, Tafo, Gold Coast, 1948 (typescript).
[56] *Ibid.*
[57] *Ibid.*

with a moisture content below 8%. Although primarily a field pest, it develops on drying trays during the wet season.[57a]

Damage to cacao trees caused by vertebrates assumed appreciable proportions in wartime, when means of control were scarce or unobtainable. Monkeys, squirrels, rats, manicou gros yeux and parrots are troublesome. Squirrels and parrots are controlled by shooting and rats and manicous by poison baits.[58] Brown pod rot, due to *Botryodiplodia theobromae* invasion, frequently follows damage to pods by vermin.[59]

Withering of leaves and defoliation through exposure to wind can cause death to cacao trees. For this reason, trees which act as windbreaks are planted to protect the crop.

Diseases of shade trees are a cause for concern on cacao plantations, because a break in the protective canopy can give rise to drought. Erythrinas suffer from a kind of "witches' broom" or galls on branches. Dieback starts after four or five weeks in older trees and after six weeks in saplings infected in Venezuela.[60] Bark and wood infection, due to *Sphaerostilbe musarum* or *Calostilbe striispora* has been recorded in Venezuela.[61]

6. Moth Infestation of Cacao Beans

When cacao beans are being dried or transported in the tropics, they are liable to be attacked by the Mediterranean flour moths *Ephestia elutella*, Hübn. *Ephestia kuhniella*, Z., and *Ephestia cautella*, Wilk. also by *Plodia interpunctella*, Hübn. The moths oviposit on cacao beans or on the sacks containing them. The period of incubation is determined by the temperature, hence beans arriving at their destination may contain moths in one or other stage of their development.[62] Infestation may occur in warehouses at the port of arrival, if sound

[57a] *Insect Infestation of Stored Food Products in Nigeria.* Her Majesty's Stationery Office, London, 1952.
[58] A. Pickles, in *Report and Proceedings of the Cocoa Research Conference, 1945.* Colonial No. 192. His Majesty's Stationery Office, London, 1945.
[59] C. A. Thorold, in *Report and Proceedings of the Cocoa Research Conference, 1945.* Colonial No. 192. His Majesty's Stationery Office, London, 1945.
[60] A. F. Posnette and M. Palma. *Trop. Agr. (Trinidad), 21,* 130 (1944).
[61] C. A. Thorold, in *Report and Proceedings of the Cocoa Research Conference 1945.* Colonial No. 192. His Majesty's Stationery Office, London, 1945.
[62] H. R. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture.* Churchill, London, 1930.

beans come in contact with infested ones, also in the factory, as the caterpillar will feed on chocolate as well as raw cacao. Precautions necessary for overcoming moth infestation in store and factory are described in Chapter VII.

Ephestia elutella is a light grey moth rather smaller in size than the familiar clothes moth. It is concerned with reproduction only, and does not eat. In its life of about a week (Fig. 12), the female lays

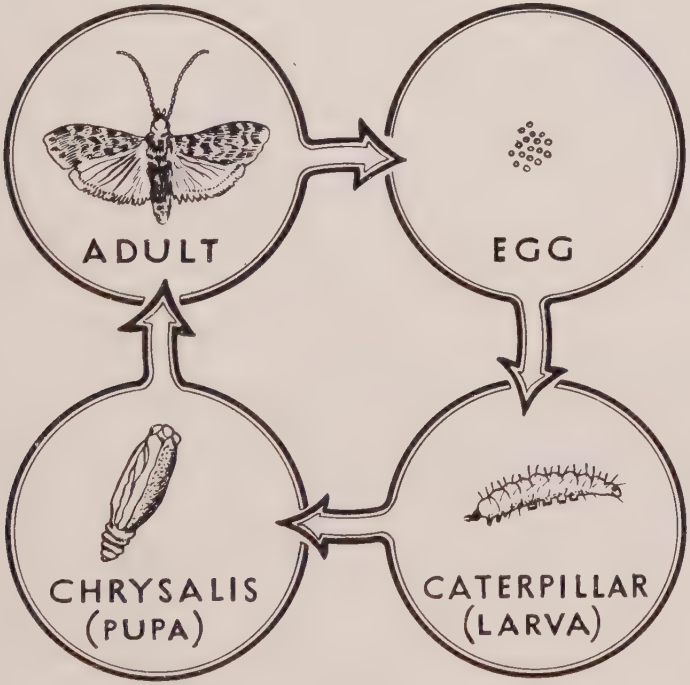


Fig. 12. Life cycle of the cocoa moth (*Ephestia elutella*) (×1.5).[63] (By permission of Dr. L. E. Campbell and Mr. L. R. Vyle.)

about 250 white eggs measuring 0.3 mm. in diameter. The eggs are to be found on food material, especially when it has been overlooked during cleaning operations, through being concealed in dark corners or crevices. When temperature conditions are favourable the larva

[63] *Machinery Design and the Control of Moth Pests in Factories*. 2nd ed. The British Food Manufacturing Industries Research Association, London, 1947.

hatches after six to ten days and feeds for a period of eight weeks before pupating. When the temperature is sufficiently high, the moth emerges from the chrysalis stage in about a week. In colder weather there is a resting stage either for cocoon or chrysalis and the emergence of the moth is delayed until the air is sufficiently warm.[63]

Three complete life cycles may be accomplished during a year,[64] but one generation is more usual.

The foregoing account of diseases and pests of cacao does not include every known agent of destruction. Imposing lists of organisms and insects capable of attacking cacao leaves, stems, shoots or pods have been drawn up by the Senior Plant Pathologist and the Senior Entomologist of the Department of Agriculture, Malaya.[65,66] Certain pests, now regarded as relatively unimportant may in the future assume greater importance. Insects and organisms indigenous to new territories where cacao planting is contemplated must be closely observed for any manifestations of preference for cacao, otherwise the tragic history of devastation in West Africa may be repeated elsewhere.

[64] H. R. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture.* Churchill, London, 1930.

[65] A. Thompson and A. Johnson, in E. E. Cheesman, *Report on Potentialities for the Cultivation of Cocoa in Malaya, Sarawak and North Borneo.* Colonial No. 230. His Majesty's Stationery Office, London, 1948.

[66] H. G. Pagden, in E. E. Cheesman, *Report on Potentialities for the Cultivation of Cocoa in Malaya, Sarawak and North Borneo.* Colonial No. 230. His Majesty's Stationery Office, London, 1948.

CHAPTER V

CHEMICAL CHANGES IN THE MATURING FRUIT

1. Development and Maturation of the Cacao Fruit

A. FERTILISATION AND DEVELOPMENT

In general, self-fertile trees are more productive than self-sterile ones. Observations on 100 clones at River Estate, Trinidad, where the plots contain mixed populations show that five out of the seven best clones are self-fertile and seven of the nine poorest ones are self-sterile. At present, it is not possible to say whether low yields from self-sterile clones are due to inadequate pollination or to certain genetic factors.[1] Pollination by insects and results of hand pollination of self-sterile and self-fertile trees are discussed in Chapter II.

The cacao flower reaches its normal size in 18 to 22 days. It is then 7 mm. long and 5 mm. in diameter when unopened. On bright days, it unfolds at 8 a.m. and remains open for eight to ten hours. The anthers burst about two hours after the flower has opened[2] and their pollen is discharged. On reaching the stigma, the pollen germinates and one hour later, the pollen tubes have penetrated about halfway down the style. The ovule is reached in about four hours. The style of a fertilised flower wilts and the ovary begins to swell. After six days, the ovary is about 4 mm. long and when the fruit is set (14 days after fertilisation) it is 7–12 mm. long.[3] Progressive changes in length, fresh and dry weight of Forastero cacao fruits during development and maturation observed by Humphries[4] are shown

[1] F. W. Cope, *Cocoa Conference 1949* (p. 86). The Cocoa, Chocolate and Confectionery Alliance, Ltd., London, 1949.
[2] M. Dejean, *Cacao Information Bull., 1,* No. 13, 1 (1948).
[3] M. Dejean, *Cacao Information Bull., 1,* No. 14, 3 (1948).
[4] E. C. Humphries, *Ann. Botany, 7,* 45 (1943).

in Table IV. Although the over-all weight of the fruit continued to increase, no change in length was observed later than 143 days after setting. Except in the earliest stages, when there was no line of demarcation, the samples of fruit examined were separated into wall and pulp. The term "pulp," generally associated with the mucilaginous substance removed from cacao seeds during fermentation, is used by Humphries to embrace all the tissue inside the fruit wall. As development proceeds, it includes an increasing amount of seed. Both fresh and dry weights of each part were determined. The weight of the

TABLE IV. AVERAGE VALUES FOR LENGTH OF CACAO FRUITS AND FRESH AND DRY WEIGHTS DURING DEVELOPMENT[a]

Age, days	Length, cm.	Fresh weight of fruit, grams	Fresh weight of wall, grams	Fresh weight of pulp, grams	Dry weight of wall, grams	Dry weight of pulp, grams	Fresh weights of wall/ pulp	Dry weights of wall/ pulp
18	1– 1.9	0.18	(0.18)	—	0.37	—	—	—
32	3– 3.9	2.30	2.13	0.17	0.43	0.022	12.4	19.5
46	5– 5.9	8.11	7.33	0.80	1.26	0.095	9.2	13.2
63	8– 8.9	29.2	25.84	3.36	4.36	0.369	7.7	11.8
73	10–10.9	54.7	46.37	8.33	6.75	0.768	5.6	8.8
87	13–13.9	156.1	117.65	38.45	15.69	3.64	3.1	4.3
107	16–16.9	346.0	248.60	97.40	34.50	18.94	2.6	1.8
143	18–18.9	478.4	356.00	122.4	49.15	26.71	2.9	1.8
170	18–18.9	496.3	378.50	117.8	50.66	43.25	3.2	1.2

[a] E. C. Humphries, *Ann. Botany*, 7, 45 (1943).

wall exceeded that of the pulp throughout development, but there was a steady decline in the ratio of wall to pulp, as regards both fresh and dry weight, up to the 143rd day, when the fresh weight ratio increased during the ripening period. The decrease in fresh weight and increase in dry weight of the pulp during ripening denote a transfer of water to the wall.

The average period of growth and maturation of the fruit is 170 days after setting and the developmental phase occupies 75 days. On the 50th day, the zygote divides and the next 25 days are spent in the preliminary development of the embryo. During the maturation phase, the period between the 75th and 87th day is one of increasing metabolic activity. From the 87th to the 143rd day, fat formation is rapid. By the 143rd day, the fruit has attained its full size and is still green. Ripening commences, as indicated by the change in the colour

of the fruit wall, and the fruit reaches maturity on the 170th day.[5] The seeds are then separate from the wall and each is surrounded by a white mucilage.

B. CHERELLE WILT

Immature cacao fruits (cherelles) are liable to physiological wilt over an unusually long period because embryo development is slow. Cherelle loss is about 46% in Trinidad and varies from 32% to 84% of fruits set in the Gold Coast.[6] By following the seasonal variations in the carbohydrate reserves of the bark and wood of cacao trees at different levels, Humphries[7] concluded that the carbohydrate content of trees bearing smaller crops was not limiting the size of crop and that some other factor was concerned. He observed that fruits tend to wilt when the maximum demand for mineral nutrients is made on the tree by the developing crop, or in the case of young trees, by a heavy flush of new leaves. During the first 75 days after cacao fruits have set, they are dependent on nutrients transported in the xylem and are consequently sensitive to water strain or competition up to the time when mineral supplies are augmented by the phloem. Until then, the fruits are susceptible to physiological wilt. Lack of potassium is an important factor in limiting the size of crop.[8]

Naundorf and Villamil[8a] claim that cherelle wilt may be reduced by spraying young fruits with a 0.2% solution of beta-naphthoxyacetic acid, followed a week later by a second spray of 0.05% of potassium alphanaphtheneacetic acid. Cherelle loss was 69.4% on untreated trees and 13.2% on sprayed trees.

C. CARBOHYDRATE AND TANNIN CHANGES

Humphries[9] followed the carbohydrate changes during development and maturation of Forastero cacao fruits. The wall and "pulp" were extracted separately with 80% alcohol. Aliquots of the extracts

[5] E. C. Humphries, *11th Ann. Report Cacao Research Imp. Coll. Trop. Agr. (Trinidad)*, 1941–43, 23 (pub. 1944).
[6] M. Dejean, *Cacao Information Bull., 1*, No. 14, 3 (1948).
[7] E. C. Humphries, *Ann. Botany, 11*, 219 (1947).
[8] E. C. Humphries, *Trop. Agr. (Trinidad), 22*, 66 (1945).
[8a] G. Naundorf and F. Villamil, *Notas Agronomicas* (Estacion Agricola Experimental de Palmira), *3* (1), 87 (1950).
[9] E. C. Humphries, *Ann. Botany, 7*, 45 (1943).

were used to determine alcohol-soluble material and soluble carbohydrates. The insoluble material was reserved for the determination of starch and fat.

TABLE V. Alcohol-soluble Material, Sugars and Glycosidic Glucose in the Wall at Different Stages of Development of the Cacao Fruit[a]

Age of fruit, days	Alcohol-soluble material, %	Glucose, %	Fructose, %	Sucrose, %	Glycosidic glucose, %
25	3.54	0.06	0.09	0.02	0.31
46	3.77	0.10	0.29	0.10	0.42
57	3.52	0.02	0.53	0.22	0.44
73	3.48	0.25	0.50	0.12	0.26
87	4.04	0.27	0.80	0.05	0.27
107	3.76	0.34	0.79	0.13	0.15
143	4.03	0.41	0.97	0.12	0.12
170	4.22	0.35	1.03	0.24	0.12

[a] E. C. Humphries, *Ann. Botany*, 7, 45 (1943).

TABLE VI. Alcohol-soluble Material, Sugars and Glycosidic Glucose in the Pulp at Different Stages of Development of the Cacao Fruit[a]

Age of fruit, days	Alcohol-soluble material, %	Glucose, %	Fructose, %	Sucrose, %	Glycosidic glucose, %
25	5.39	1.17	0.71	Nil	Nil
46	4.67	0.82	0.50	Nil	0.03
57	5.05	0.97	0.89	Nil	0.07
73	4.85	0.82	0.78	0.05	0.12
87	4.61	0.67	1.21	0.51	0.14
107	6.09	0.55	0.82	0.88	0.50
143	6.46	0.64	0.66	1.56	0.38
170	9.68	1.09	1.06	2.90	0.73

[a] E. C. Humphries, *Ann. Botany*, 7, 45 (1943).

The fluctuations of alcohol-soluble matter, sugars and glycosidic glucose in the wall of the developing fruit are presented in Table V.[10] Corresponding values for the pulp are given in Table VI.[11]

Up to the time of the division of the zygote (about the 50th

[10] E. C. Humphries, *Am. Botany*, 7, 45 (1943).
[11] *Ibid.*

day) fructose (levulose) increases, glucose (dextrose) increases slightly at first and sucrose increases in the wall, attaining its maximum by the 57th day. In the pulp, fructose and glucose decline at first and later increase until they are approximately equal. No sucrose is present at this stage.

From the 52nd to the 73rd day, carbohydrate changes in the wall are not well defined. In the pulp, fructose and glucose are still almost equal, but exhibit a downward trend.

Between the 73rd and the 87th day, glucose decreases in the wall and then increases to its original value, fructose increases steadily

TABLE VII. CHANGES IN STARCH CONTENT OF WALL AND PULP AND FAT CONTENT OF PULP OF THE CACAO FRUIT AT DIFFERENT STAGES OF DEVELOPMENT[a]

	Wall	Pulp		
Age of fruit, days	Takadiastase hydrolysable products, % dry weight	Takadiastase hydrolysable products, % dry weight	Ether-soluble material, % dry weight	Saponification value of ether extract
25	0.25	—	—	—
57	0.60	0.88	—	—
73	0.45	0.77	—	—
87	0.51	1.59	0.45	—
93	0.49	2.94	11.17	306
107	0.53	4.04	31.49	232
143	—	5.02	44.31	221
170	0.41	5.34	47.64	222

[a] E. C. Humphries, *Ann. Botany*, 7, 45 (1943).

and sucrose decreases. In the pulp, glucose shows a downward trend, fructose decreases at first and then reaches its maximum. Towards the end of the period, sucrose formation occurs.

From the 87th to the 143rd day, glucose and fructose fluctuate in the wall and sucrose remains practically constant. Fructose decreases and glucose is practically unaltered in the pulp. There is a rapid accumulation of sucrose. Anthocyanin formation, indicated by colour development in the cotyledons, can be followed by the increase in glycosidic-glucose. The anthocyanin pigments of cacao are described in Chapter VI. Anthocyanin production is governed by a number of factors, including gene dosage.[12] No anthocyanins are

[12] W. J. C. Lawrence, *Nature, 163,* 626 (1949).

present in Criollo cacao. Leucoanthocyanins are present in all varieties of cacao seeds. The rapid accumulation of starch is demonstrated by increase in takadiastase-hydrolysable products (see Table VII).[13] Holden[14] has shown that under given conditions takadiastase is also capable of hydrolysing pectin.

During the period of ripening (143rd to 170th days), fructose increases and glucose decreases in the fruit wall. Sucrose increases slightly. In the pulp, sucrose and starch accumulate, glucose and fructose again become equal and glycosidic-glucose attains its maximum value.

In a further series of fruit samples, kernels and white tissue plus testas were examined separately during the ripening period. It was found that the concentrations of glucose and fructose in the white tissue exceeded those of the kernels. Except in the case of a sample consisting of almost ripe fruits, more sucrose was present in the white tissues than in the kernels. The three sugars accounted for more than 70% of the alcohol-soluble material of the white tissues. In the kernels only 30% of the alcohol-soluble material consisted of sugars.

Humphries discusses the possibility that further investigation of the non-sugar fraction of alcohol-soluble material in the wall and pulp may lead to information concerning precursors of the seed fat. In the wall, the proportion of sugars to alcohol-soluble solids increases steadily and reaches a maximum of 40% in about 100 days. In the pulp, the ratio of sugars to alcohol-soluble matter decreases during the early stages and then rises to a maximum in about 70 days. Between that time and the 90th day the proportion of sugars falls off and then rises sharply until at maturity the sugar content surpasses the non-sugar content (see Tables V and VI).

Macdonald[15] found little significant change in the tannin content of Trinidad Calabacillo and Forastero beans and Venezuelan Criollo beans after they had reached three-quarters of their mature size. Unripe Calabacillo beans contain rather more tannin than ripe ones. The reverse is true of Forastero and Criollo beans.

[13] E. C. Humphries, *Ann. Botany*, *7*, 45 (1943).
[14] M. Holden, *Biochem. J.*, *47*, 426 (1950).
[15] J. A. Macdonald, *6th Ann. Report Cacao Research Imp. Coll. Trop. Agr. (Trinidad)*, 1936, 34 (pub. 1937).

D. FAT FORMATION

Seed fats are probably synthesised from sugars. No intermediate products have been isolated. In the early stages, free fatty acids predominate. Neutral fats (triglycerides) are formed at a comparatively late stage. As ripening proceeds, the proportion of unsaturated acids increases.[16] The relative proportions of fatty acids in cacao fat are subject to slight variations in different types of mature seeds. Average values for saturated acids are palmitic 24.4%, stearic 35.4% and for unsaturated acids, oleic 38.1% and linoleic 2.1%.[17]

Humphries[18] has shown that fat accumulates rapidly in the pulp between the 87th and 143rd days (see Table VII). Just before ripening, a small amount of yellowish fat was present in the testa, but none was present in the testas of ripe seeds. Saponification values of ether extracts of the pulp decrease as the fruit approaches maturity. This progressive decrease (recorded in Table VII) may be due to the presence of an increasing proportion of neutral fat built up from the fatty acids formed.

E. NITROGEN METABOLISM

The relative (logarithmic) rates of uptake of nitrogen and dry matter are constant and equal in the wall and pulp of cacao fruits between the 27th and 57th days. In the period between the 57th and 107th days, the uptake of nitrogen is maintained in the pulp, but is lower in the wall.[19]

Macdonald[20] states that theobromine increases greatly in the cacao seed during ripening and reaches a maximum when the fruit is fully ripe. There is no change when the pods are allowed to remain on the tree to become overripe. Skins and mucilage contain little or no theobromine. There is practically no difference between the theobromine content of Venezuelan Criollo, Trinidad Calabacillo and Forastero beans.

[16] T. P. Hilditch, *J. Chem. Soc.*, 243 (1948).
[17] T. P. Hilditch and W. J. Stainsby, *J. Soc. Chem. Ind., 55*, 95 (1936).
[18] E. C. Humphries, *Ann. Botany, 7*, 45 (1943).
[19] E. C. Humphries, *Ann. Botany, 8*, 57 (1944).
[20] J. A. Macdonald, *6th Ann. Report Cacao Research Imp. Coll. Trop. Agr. (Trinidad)*, 1936, 34 (pub. 1937).

F. UPTAKE OF MINERAL CONSTITUENTS

Humphries[21,22] observed a continuous increase in mineral matter, expressed as the percentage of residual dry matter (total solids less sugars, starch and fat) in the fruit during 143 days. When ripening commences, a decrease occurs.

As with nitrogen, the relative rates of uptake of phosphorus, potassium and calcium are constant and equal in both wall and pulp during the period of development from the 25th to the 57th days. Between the 57th and the 107th days, uptake is maintained in the pulp but is diminishing in the wall.

After 93 days, the uptake of phosphorus and magnesium is accelerated. During ripening, phosphorus appears to migrate from the wall to the pulp. The rate of calcium uptake declines after 80 days.

From the respective ratios of potassium, phosphorus and magnesium uptake to calcium uptake it would appear that for the first 75 days the fruit receives these elements mainly by the transpiration stream (xylem transport). After 75 days the ratio of each of these elements to calcium rises steadily. By assuming that calcium is not phloem-mobile and that the relative proportions of the mineral elements in the transport stream are reasonably constant, it is possible to assess the comparative importance of xylem and phloem transport during fruit development. The steady rise in the ratios of potassium, phosphorus and magnesium to calcium after 75 days indicates that additional sources of potassium, phosphorus and magnesium become available via the phloem.

Variations in the mineral constituents of the wall at successive stages of development, expressed as percentages of residual dry weight (total solids less carbohydrates) are given in Table VIII.[23] Results for pulp on residual dry weight (total solids less carbohydrate and fat) appear in Table IX.[24] Insufficient material was available for analysis of the pulp from fruits less than 52 days after setting. In these experiments, phosphorus was determined by molybdenum blue development, using α-aminonaphthosulphonic acid as reducing agent, potassium by precipitation with sodium cobaltinitrite and subsequent oxidation with permanganate, calcium by precipitation as oxalate and

[21] E. C. Humphries, *Ann. Botany, 8*, 57 (1944).
[22] E. C. Humphries, *Trop. Agr. (Trinidad), 22*, 66 (1945).
[23] E. C. Humphries, *Ann. Botany, 8*, 57 (1944).
[24] *Ibid.*

TABLE VIII. Mineral Constituents in the Wall at Successive Stages of Development of the Cacao Fruit Expressed as a Percentage of Residual Dry Weight[a]

Days	Ash	P	K	Ca	Mg
25	9.12	0.36	2.91	1.30	0.74
46	9.66	0.34	2.84	1.34	0.59
57	9.46	0.32	2.69	1.30	0.54
73	9.47	0.34	2.79	1.21	0.51
87	8.82	0.28	2.68	0.95	0.45
107	7.93	0.21	2.52	0.69	0.37
143	8.32	0.21	2.79	0.71	0.34
170	10.23	0.18	3.86	0.62	0.36

[a] E. C. Humphries, *Ann. Botany, 8,* 57 (1944).

TABLE IX. Mineral Constituents in the Pulp at Successive Stages of Development of the Cacao Fruit, Expressed as a Percentage of the Residual Dry Weight[a]

Days	Total ash	P	K	Ca	Mg
57	8.74	0.53	3.11	0.75	1.14
78	10.07	0.57	3.08	1.02	0.78
87	11.07	0.61	3.65	0.97	0.69
99	11.38	0.70	3.83	0.67	0.81
122	13.81	0.89	4.70	0.59	0.92
143	16.02	1.05	5.50	0.67	1.13
170	12.41	1.20	3.99	0.49	1.19

[a] E. C. Humphries, *Ann. Botany, 8,* 57 (1944).

oxidation with permanganate, and magnesium by weighing as pyrophosphate.

G. EFFECT OF RAINFALL DURING RIPENING PERIOD

To determine the influence of rainfall on the development of the cacao fruit, Humphries[25] made observations over a period of 26 months on the average weight of fresh cacao per pod and the corresponding rainfall during the 170 days of development and ripening.

An analysis of the record reveals that when less than 10 inches of rain fell, the average yield was 3.25 oz. per pod; for 10–20 inches it was 3.5 oz.; while 20–30 inches produced an average yield of 3.6 oz.,

[25] E. C. Humphries, *10th Ann. Report Cacao Research Imp. Coll. Trop. Agr. (Trinidad),* 1940 (pub. 1941).

30–40 inches showed a yield of only 3.45 oz. The maximum yield of 3.9 oz. was produced during periods with a rainfall of 40–50 inches. When over 50 inches of rain fell, the average yield was 3.65 oz. The minimum yield was therefore obtained during periods of comparative drought and the amount of rainfall most favourable for yield was 40–50 inches. Presumably leaching of nutrients becomes a factor when rainfall exceeds 50 inches during the period of development and maturation of the fruit.

2. Composition of the Mature Cacao Fruit

As the pod wall is a waste product, very little interest has been evoked in its composition. According to the average values given in Table IV for the ripe Forastero fruit (170 days), the pod wall accounts for 76% of the whole fruit, and its moisture content is 86.6%. From Table V, the total sugars at maturity amount to 1.62% (glucose 0.35%, fructose 1.03% and sucrose 0.24%) and the content of glycosidic glucose is 0.12%. The balance of alcoholic extract due to non-sugars is 2.48%. The ash content, calculated as a percentage of the original wall, is 1.2%—and the starch content on the same basis is 0.05%. According to Humphries[26] the remainder of the solid matter consists largely of mucilage.

Although much attention has been devoted to the composition of different varieties of commercial cacao beans, no recent work has appeared giving a complete analysis of the fruit as harvested. Knapp and Churchman[27] investigated the composition of dried unfermented cacao kernels. More than half a century has elapsed since Harrison[28] published the results of analysis of the fresh husks, skins and pulp and kernels of Forastero and Calabacillo (now regarded as a sub-group of Forastero) cacao which are presented in Table X. In the light of recent knowledge concerning cacao tannin fractions and pigments, and as a result of the more selective analytical methods now available, certain of the figures tabulated cannot now be regarded as accurate.

[26] E. C. Humphries, *Ann. Botany*, *7*, 45 (1943).
[27] Quoted in A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.
[28] J. B. Harrison, *Rept. Agr. Sta. Brit. Guiana*, 1897; R. Whymper, *Cocoa and Chocolate, Their Chemistry and Manufacture*, 2nd ed., Churchill, London, 1921; C. J. J. van Hall, *Cocoa*, Macmillan, London, 1914.

TABLE X. Composition of Ripe Cacao Fruits[a]

	Kernels		Cuticles and pulp		Fruit husks	
	Calabacillo, %	Forastero, %	Calabacillo, %	Forastero, %	Calabacillo, %	Forastero, %
Moisture	37.6	36.6	87.6	83.0	82.9	84.5
Albuminoids	6.7	4.8	0.9	0.3	0.8	1.0
Theobromine	1.4	0.8	0.2	0.05	0.1	0.1
Caffeine	0.1	0.2	0.3	Nil	Nil	Nil
Other nitrogen compounds	0.5	2.8	Trace	0.05	0.2	Nil
Fat	29.3	30.6	0.4	0.4	0.1	0.1
Sucrose	Trace	0.2	0.1	1.0	Trace	1.0
Starch	3.8	6.0	0.9	1.3	0.5	0.4
Astringents	5.0	4.9	0.4	0.1	2.2	0.2
Pectic substances	0.7	1.4	0.8	1.1	1.7	1.0
Cocoa red	3.0	1.5	0.5	0.7	0.7	0.6
Digestible fibre	5.1	2.8	4.7	6.6	5.4	4.0
Woody fibre	3.0	3.5	1.3	2.5	3.3	5.3
Free acid (tartaric)[b]	0.1	Nil	0.4	0.6	0.3	0.3
Acetic acid	Nil	Nil	Nil	Trace	0.1	0.1
Combined acid (tartaric)[b]	0.5	0.5	0.3	0.35	0.8	0.6
Fe_2O_3	0.03	0.03	Nil	0.01	0.01	0.01
MgO	0.32	0.45	0.11	0.07	0.10	0.10
CaO	0.05	0.11	0.05	0.03	0.04	0.04
K_2O	0.84	0.64	0.19	0.25	0.45	0.36
Na_2O	0.24	0.07	0.04	0.01	0.04	0.07
SiO_2	0.02	0.02	Nil	Nil	0.01	0.01
SO_3	0.08	0.05	0.02	0.03	0.04	0.03
P_2O_5	0.75	1.05	0.12	0.10	0.08	0.10
Cl	0.02	0.03	0.02	0.06	0.03	0.03

[a] J. B. Harrison, *Rept. Agric. Sta. Brit. Guiana*, 1897; R. Whymper, *Cocoa and Chocolate, Their Chemistry and Manufacture*, 2nd ed., Churchill, London, 1921; C. J. J. van Hall, *Cocoa*, Macmillan, London, 1914.

[b] It is now known that citric and oxalic acids and not tartaric acid are present in cacao.

For discussions on leucoanthocyanins, total cyanidin and cyanin in cacao beans see Chapter VI, 7C(4); boron in cacao, Chapter VIII, 3E; glucose and fructose, this chapter, 1C and organic acids in cacao beans Chapter VIII, 1.

CHAPTER VI

FERMENTATION AND DRYING

1. Objects of Fermentation

The curing process or fermentation is the first stage in the preparation of cacao beans for the market. It is followed by drying, whereby certain changes set in motion during fermentation are continued. This centuries' old custom of curing, whether performed by the simple methods used by peasant farmers or conducted under scientific control, as in the larger plantations, is the outcome of the necessity to free the beans from the tenaciously adhering pulp with which they are surrounded and also to prevent germination. The main purpose of the treatment is to prepare a stable product possessing the qualities of flavour and aroma desirable for the manufacture of cocoa and chocolate.

The chemical and biological changes taking place result in the breakdown and removal of the pulp, and cause the death of the bean, with consequent release of enzymes capable of bringing about reduction of astringency. The altered texture of the seed coat facilitates its removal during subsequent processing.

The richness of colour of the manufactured article is dependent on the attainment of the right degree of fermentation. Both shape and colour of the bean undergo alterations which serve to indicate when fermentation is complete. Well-fermented beans are plump and insufficiently fermented ones are flat. The interior of white beans becomes light cinnamon in colour and that of purple beans changes to chocolate brown. A purple-brown shade is indicative of incomplete fermentation. The cotyledons of unfermented beans are slatey-coloured.

2. Harvesting

The ideal time for harvesting is about one month after the pods are fully grown and they should be, in so far as possible, of uniform

Fig. 13. Opening collected pods. Gold Coast. (Original photograph by J. Nicol.)

Fig. 14. Collecting the beans for fermentation. Gold Coast. (Original photograph by J. Nicol.)

ripeness. Flavour will be sacrificed by the inclusion of under-ripe or over-ripe beans. When the pods are over-ripe, the pulp surrounding the beans loses its value as a nutrient medium for organisms.

The pods are cut from the tree with a sharp knife. To reach the higher ones, the knife is mounted on a rod. The operation requires skill, for it is necessary to avoid injury of the cushion which is the site of the succeeding years' flowers.

When a pile of pods has been collected (Fig. 13) they are sliced open and the beans are withdrawn, either by hand or with a wooden spoon, and placed in baskets (Fig. 14). Vigilance is required to make sure that the placentas are discarded, otherwise the beans will continue to adhere in clusters which encourage undesirable mould growth. Any cut beans should be rejected as they are liable to be attacked by insects. When the seeds of diseased pods are sound, they can be included, but spoilage sometimes occurs when the pulp has deteriorated. In districts where pod rot is rife, the empty pods should be collected and burnt.

In most cacao-producing countries there are two harvests, one in the rainy and the other in the dry season. In the latter, when there is shortage of pulp, the deficiency is sometimes rectified by spraying the beans with diluted molasses.

3. Methods of Fermentation

Whether the equipment is simple or elaborate, satisfactory fermentation will only take place under conditions which maintain the heat, allow the sweatings to drain off and provide adequate access of air.

How far these conditions are fulfilled depends on the method of fermentation. The most primitive arrangement is to place the beans in a hole in the ground. This procedure has many undesirable features, such as lack of aeration and drainage, and will result in an uneven product. Fortunately the practice is rapidly becoming obsolete. A simple method which gives better results, although not providing adequate drainage, is to build up a conical heap of about 5 cwt. of beans and cover it with plantain leaves (Figs. 15 and 16). This arrangement is used by the peasant farmers in West Africa. If the heap is too small, the temperature fails to rise sufficiently for the proper sequence of yeasts to take place and germination is encouraged.

Fig. 15. Covering fermentation heap with plantain leaves. Gold Coast. (Original photograph by J. Nicol.)

Fig. 16. Fermentation heap. Gold Coast. (Original photograph by J. Nicol.)

Germinated beans give rise to bitter-flavoured products. In the Gold Coast, the average content of germinated beans is about 4%.[1] Soil deterioration occurs in patches which have supported the heaps. Better drainage is ensured by placing the beans in rough frames made from plantain stems or in bamboo frames raised off the ground.

A more uniform product is obtained by using a series of perforated or slatted boxes made of slate, stone, cement or wood constructed without nails, because iron discolours the beans and spoils their flavour. Such receptacles are known as sweat boxes and are usually arranged in three tiers. The contents of the top box are transferred to the second box after 48 hours and emptied into the third one 48 hours later. The beans are thus effectively mixed and aerated.

Kaden[2] recommends a four-tier system of boxes stepwise inside a shed designed to protect the beans from cold winds. Only the top and second boxes are perforated. The depth of the layer of beans should preferably be about 50 cm. and never more than 80 cm. To prevent the beans from drying out, the liquefied pulp is poured back over them. Fermentation by this method can sometimes be completed on the fourth or fifth day.

When very large quantities of beans are dealt with, they are fermented in vats with sloping floors. In Ceylon, the vats are aerated with bamboo shoots.

The practice of washing fermented beans to remove adhering pulp has been criticised by Knapp[3] on the ground that it makes the seed coat more fragile. Kaden[4] contends that a wash is beneficial if the beans are sieved after 15 minutes' treatment, and states that when ordinary cacao is washed in this way, the overall loss in bean dry weight (2–3%) is confined to the seed coat. Washing is apt to remove dry matter from the cotyledons of choicer varieties of cacao.

In the New Zealand Reparation Estates of Samoa, good results are obtained after washing. The beans are fermented in boxes covered with several thicknesses of heavy burlap. They are turned over at intervals of twelve hours until the fourth day, when they are transferred to perforated circulating drums which are placed in tanks of water. The beans are drained in perforated wagons and then partially

[1] R. V. Wadsworth, in *Cocoa Conference 1949.* The Cocoa, Chocolate and Confectionery Alliance, London, p. 73, 1949.
[2] O. F. Kaden, *Gordian, 50,* No. 1196, 12 (1950).
[3] A. W. Knapp, *Cacao Fermentation.* Bale, Sons & Curnow, London, 1937.
[4] O. F. Kaden, *Gordian, 50,* No. 1196, 12 (1950).

dried by hot air. Later they are tumbled in segmented drums while a current of hot air is passed. Tumbling gives the beans a high polish.[5]

A good supply of water is required for washing beans. This is not everywhere available in the Gold Coast.

4. Period of Fermentation

Criollo beans are less astringent than Forastero varieties and require a shorter time for complete fermentation. White and coloured beans occurring in the pods of hybrids should be fermented separately, otherwise the white ones will be over-fermented and flavourless. The astringency of Criollo cacao is lowered to a satisfactory level after two or three days' fermentation, whereas Forastero beans require five to seven days' treatment.

Cacao grown in Ecuador (Arriba) undergoes only a partial fermentation. The beans are laid out on drying platforms and exposed to the sun for short periods. Summer Arriba cacao (main crop) has more flavour than the light crop, possibly because it is slightly more fermented as a result of the larger bulk treated.

Observations in Trinidad indicate that storage of pods for a week before opening causes a more rapid rise of temperature and improves the flavour.[6]

Various suggestions have been made for shortening the period of fermentation. Nicholls[7] favoured the introduction of a pure yeast culture as a starter. Knapp[8] recommended that pulp which had drained after one day's fermentation might be used to sprinkle over the next batch of beans. Chierrichetti[9] carried out trials using *Pseudomonas lindneri* as a starter. He recommended that workers engaged in removing beans from pods should dip their hands in the culture from time to time to ensure incorporation of the organism throughout the mass. Thus fermentation is already in progress while the beans are being transported to the fermenting shed. It is claimed that the organism inhibits the growth of putrefactive bacteria. Chierrichetti

[5] D. Butchart, *Cacao Information Bulletin, 1,* No. 24, 2 (1949).
[6] B. L. Hancock, in *Cocoa Conference 1949.* The Cocoa, Chocolate and Confectionery Alliance, London, p. 75, 1949.
[7] L. Nicholls, in H. H. Smith, *The Fermentation of Cacao.* Bale, Sons & Danielsson, London, 1913.
[8] A. W. Knapp, *J. Soc. Chem. Industry, 43,* 402, 431 (1924).
[9] G. Chierrichetti, *Bull. Officiel de l'Office Internat. du Cacao et du Chocolat, 9,* 335 (1939).

suggested that the culture might be used for re-fermentation of poorly fermented beans after arrival in the importing country. He reported that cacao treated in this manner developed a fine aroma and flavour.

So far, none of these methods has been adopted to any significant extent and reliance continues to be placed on airborne organisms.

It was formerly believed that the vinegar fly, *Drosophila melanogaster*, played an important part as a vector for acetic acid bacteria and that its presence should therefore be encouraged as an accelerator. Briton-Jones[10] considers that this is highly undesirable, on account of the maggot stage of its life cycle.

5. Drying

Fermented beans must be dried to a final moisture content of about 6 to 8% to ensure good keeping qualities. Flavour development is dependent on the care exercised, particularly during the early stage of the process.

A. SUN-DRYING

A simple yet satisfactory method for drying small lots of beans is used in the Gold Coast. They are spread on raffia or palm leaf mats supported on trestle tables (Fig. 17). The beans are turned occasionally to allow even drying. At nightfall or during rain, the mats are rolled up with the beans inside and carried indoors.

Larger quantities of beans are laid on raised platforms equipped with sliding roofs which can be drawn across for protection during rain or low night temperatures, or even when heat is excessive. Alternatively, drying sheds are constructed with movable trays which are pulled out in the daytime (Fig. 18).

Exposure of the beans to intense heat, especially during the early stages, causes the skins to wrinkle and their surface to harden before the desired enzyme changes can take place within the cotyledons. The temperature range 45° to 60°C. is suitable for satisfactory drying.[11]

Sun-dried beans are often preferred because their flavour is considered to be superior to that of artificially dried beans owing to more efficient aeration.

[10] H. R. Briton-Jones, *The Diseases and Curing of Cacao*. Macmillan, London, 1934.

[11] A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.

Fig. 17. Cacao beans laid out to dry on mats. Gold Coast. (Original photograph by J. Nicol.)

Fig. 18. Drying sheds with movable trays. Gold Coast. (Original photograph by J. Nicol.)

Solar irradiation of ergosterol originating from dried yeast attached to the seed coat (shell) produces varying, but appreciable amounts of calciferol (vitamin D). This enhances the value of sun-dried shell when it is used as cattle fodder. Calciferol is also present in the radicle (germ) which is frequently included with the kernels used in the manufacture of cacao products.[12]

Sun-drying produces unsatisfactory cacao in districts where the main harvest occurs during the rainy season, on account of spoilage by mould contamination.

B. ARTIFICAL DRYING

Sun-drying takes about six days in dry weather or as long as three weeks in moist climates. Artificial heat shortens the time to three or four days and by vacuum methods the time is reduced to about 36 hours.

When beans are laid out on a heated platform, they are liable to be contaminated by the fuel gases and a "hammy" flavour is developed. It is therefore preferable to use machinery for the circulation of hot air or some form of vacuum drying. Details of drying equipment are described by Hudson,[13] Whymper,[14] Fincke[15] and Knapp.[16]

If drying is too rapid in the initial stage, the tannin constituents in the kernels will not be sufficiently oxidised. Vacuum drying prevents oxidation and should preferably be postponed until the final stage. Even then, it is possible that some of the desirable aromatic constituents may be sacrificed.

Vyle[17] has described the conditions essential for drying Criollo cacao. During the first stage of slow drying, the skin must be set in a stretched condition and its moisture content sufficiently reduced to resist mould growth. The second stage is a period of oxidation, during which time aroma develops and astringency is lowered. This is followed by a final rapid drying to remove excess moisture.

[12] A. W. Knapp and K. H. Coward, *Analyst, 59,* 474 (1934).
[13] G. S. Hudson, in H. H. Smith, *The Fermentation of Cacao.* Bale, Sons & Danielsson, London, 1913.
[14] R. Whymper, *Cocoa and Chocolate. Their Chemistry and Manufacture.* 2nd ed., Churchill, London, 1921.
[15] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[16] A. W. Knapp, *Cacao Fermentation.* Bale, Sons & Curnow, London, 1937.
[17] L. R. Vyle, in *Cocoa Conference 1949.* The Cocoa, Chocolate and Confectionery Alliance, London, p. 83, 1949.

6. The Pulp and Sweatings

A. COMPOSITION OF THE PULP

The pulp is the white, or sometimes pale pink, mucilaginous mass in which the beans are embedded. Nicholls[18] reported the following range of composition for pulps examined in St. Lucia: moisture: 79.73–88.5%, albuminoids, astringents, etc.: 0.56–0.72%, dextrose: 8.34–13.12%, sucrose: 0.40–0.95%, starch: traces, non-volatile acidity, calculated as tartaric acid: 0.25–0.42%, iron oxide: 0.03%, salts (potassium, sodium, calcium, magnesium): 0.40–0.45%, volatile acids and alcohol: absent. Hardy[19] established that the non-volatile acid was citric acid and not tartaric acid. The initial pH of cacao pulp is a little below 4.0. Such a medium is eminently suitable for the propagation of yeasts.

By using chromatographic methods, Forsyth[20] was able to follow the changes in sucrose, dextrose and levulose content during fermentation. Raffinose was not found. Hardy's statement that the only free acid present is citric was confirmed. By two-dimensional paper chromatograms, the chief amino acids were found to be glutamic, aspartic and asparagine.

B. CHANGES DURING FERMENTATION

Two major changes occur during the fermentation of the pulp, the first being the conversion of the sugars into alcohol. This is brought about by a succession of yeasts. At the same time, the cells of the pulp are broken down, presumably by pectic enzymes, so that it is reduced to a turbid, yellow liquid and gradually trickles away. The drainings, which vary in composition from day to day as fermentation proceeds, are known as "sweatings."

The second stage is an acetic acid fermentation caused by the action of bacteria on the alcohol.

When the time of fermentation is unduly prolonged, the mass is attacked by putrefactive bacteria and moulds. Similar deterioration is liable to occur through neglecting to turn over the beans. Moulds, though harmless when their attack is confined to the surface of the

[18] L. Nicholls, in H. H. Smith, *The Fermentation of Cacao*. Bale, Sons & Danielsson, London, 1913.
[19] F. Hardy, *J. Soc. Chem. Industry, 44*, 305T (1925).
[20] W. G. C. Forsyth, *Nature, 164*, 26 (1949).

beans, exert a deleterious effect when penetration of the interior tissues has occurred.

Sweatings are at first comparatively rich in sugars and later contain alcohol and acetic acid. Although schemes have been proposed for their conversion into alcoholic beverages, industrial alcohol and vinegar, they are generally written off as a waste product. Knapp[21] reported the presence of 2% of pectic substance and suggested that it might be profitable to extract it for the purpose of jelly making.

Knapp[22] investigated the composition of sweatings drawn in Trinidad after 18, 19 and 40–42 hours' fermentation and preserved with formalin before being despatched to England for analysis. Their respective specific gravities were 1.066, 1.050 and 1.039; total solids were 15.2, 10.9 and 7.9%; volatile acidity, calculated as acetic acid, for the corresponding periods 1.4, 1.2 and 2.0%. It would therefore appear that action by acetic acid bacteria had commenced before the forty-second hour. A slight increase of theobromine content was observed after 19 hours. No caffeine was initially present, but a trace was recorded after 19 hours. These substances had evidently diffused into the pulp from the tissues of the bean.

C. THE MICROORGANISMS

(1) ALCOHOLIC FERMENTATION

Very few organisms are to be found in fresh cacao pulp. After 24 hours' exposure to the air, it becomes densely populated by yeasts. The flora vary according to geographical situation and the types present may possibly have some bearing on the subtle differences of flavour which are associated with cacao grown in different localities, just as particular yeasts influence ester development in wines.

The following list of yeasts found in fermenting cacao is based on Knapp's survey of the literature on the subject.[23]

Saccharomyces cerevisiae, reported on Trinidad cacao by Chittenden in 1899.

Saccharomyces theobromae, Preyer, discovered by Preyer in 1901 on Ceylon cacao, has been renamed *Eutorulopsis theobromae.*

Saccharomyces ellipsoideus and *Saccharomyces apiculatus* were observed on cacao from Puerto Rico by Loew in 1907.

[21] A. W. Knapp, *Cacao Fermentation.* Bale, Sons & Curnow, London, 1937.
[22] *Ibid.*
[23] *Ibid.*

Saccharomyces anomalus, found by Bainbridge and Davies on Jamaican cacao in 1912.

The occurrence of the above yeasts was not confined to the particular areas mentioned and in many instances several varieties were reported on the cacao from one district. Yeasts which flourish in the initial stages later give place to others better adapted to the changing conditions of temperature and pH. Ciferri,[24] who made an exhaustive study of this aspect, listed the following yeasts as being normally present on fermenting cacao in San Domingo:

Eutorulopsis theobromae throughout fermentation,

Endomyces anomalus (*S. anomalus*), *Klockeria domingensis* and

Klockeria cacaoicola (sub species of *S. apiculatus*) in the initial stages,

Saccharomyces ellpsoideus, Saccharomyces bussei,
Saccharomyces ellipsoideus var. domingensis and
Torulopsis lilienfeld-toallii in the later stages.

Many enzymes participate in the breakdown of cacao pulp, resulting in the hydrolysis of polysaccharides and the reduction of disaccharides like sucrose to monosaccharides by a series of reactions not yet completely understood. The monosaccharides are then fermented by the "zymase complex" of yeasts and ethyl alcohol is produced. It is now known that alcoholic fermentation involves many intermediary steps as well as several alternate paths. Many of these reactions are exothermic and will thus raise the temperature of the fermenting cacao beans. Because it is desirable that the rise in temperature should be sufficiently rapid throughout the mass to kill the radicle before germination can take place, it is preferable to ferment large quantities of cacao at a time.

(2) ACETIC ACID FERMENTATION

After the zenith of yeast activity has been passed, a large proportion of the pulp has already trickled away in the form of sweatings. The composition of the remainder is favourable to the growth of bacteria, which now carry on the attack and are present in copious quantities 60 hours after the beginning of fermentation.

Acetic acid bacteria predominate. Eckmann[25] identified *Aceto-*

[24] R. Ciferri, *J. Dept. Agr. Puerto Rico, 15,* 223 (1931).
[25] C. Eckmann, *Acetic Bacteria from Cacao Fermentation.* Noske, Leipsig, 1928.

bacter xylinum, Bacterium xylinoides, B. orleanense and *A. ascendens.* These organisms oxidise alcohol to acetic acid. The reaction causes a rise in temperature. Lactic acid bacteria were observed on fermenting cacao in Trinidad by Chittenden.[26] Their presence in large numbers has been confirmed on fermenting beans in Java.[27] More recent examinations of the flora of Trinidad sweat boxes[28] indicate that lactic acid bacteria flourish only during the second day of fermentation, when the conditions prevailing tend to depress the growth of more aerobic bacteria. As soon as the collapse of the pulp cells permits better aeration, they are quickly outnumbered by acetic acid bacteria. It seems unlikely that lactic acid bacteria are of any importance in the fermentation process.

Vyle[29] states that acid production should be avoided during fermentation of Venezuelan Criollo.

Knapp[30] discusses the effect of acetic acid on aroma, due to its ester-forming properties and hydrolysing effect on combined theobromine, but he points out that its presence can also be disadvantageous because it retards the growth of yeasts and diminishes tannin oxidation.

Cacao becomes contaminated by putrefactive bacteria when fermentation is unduly prolonged. The presence of *B. subtilis* was reported in Jamaica and mesenteric species were found on Gold Coast cacao.[30]

(3) MOULDS

Cacao becomes contaminated with moulds when aeration is restricted, as, for instance in unturned heaps of beans. The moulds most commonly occurring are *Aspergilli,* which flourish at temperatures between 37° and 45°C. Whilst a coating of mould on the skin is neither unusual nor harmful, penetration of the cotyledons will cause spoilage of both colour and flavour which persists throughout the later processes. The presence of *Aspergillus fumigatus* is especially devastating, because it attacks cellulose and pentosans in the seed coat and paves the way for penetration of other moulds within the bean.

[26] A. W. Knapp, *Cacao Fermentation.* Bale, Sons & Curnow, London, 1937.
[27] P. A. Roelofsen and G. Giesberger, *Arch. Koffiecult, 16,* 1 (1947).
[28] W. G. C. Forsyth and J. E. Rombouts, *Cocoa Conference 1951.* The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1951.
[29] L. R. Vyle, in *Cocoa Conference 1949.* The Cocoa, Chocolate and Confectionery Alliance, London, p. 84, 1949.

Moulds on fermenting cacao mentioned by Knapp[30] are *Penicillium spp.*, recorded by Preyer in Ceylon, *Aspergillus niger* and *Pseudo-absidia vulgaris* observed by Lutz on St. Thomé cacao, *Aspergillus glaucus, Penicillium glaucum* and *Oidium lactis* reported by Steinmann in Java, *Aspergillus flavus, Aspergillus tamarii* and *Mucor spp.* observed by Schwartz and Thom in the Gold Coast and *Aspergillus fumigatus* and *Cymomucor buntingii* identified in Gold Coast cacao by Bunting.

(4) MICROORGANISMS FOUND IN LABORATORY EXPERIMENTS ON FERMENTING CACAO

Hoynak, Polansky and Stone[31] conducted laboratory fermentations to investigate the nature and behaviour of microorganisms on Costa Rican cacao. Refrigerated cacao fruits were transported to Pennsylvania and opened three weeks after harvesting. The beans, which were found to be sterile, were placed in crocks with lids and inoculated with organisms present on the pod husks. Fermentations were initiated at 20° to 25°C., 36° and 45°C. Plating indicated the presence of torulae and moulds with yeastlike activity, such as *Monilia* and *Oöspora*. No spore-forming yeasts were found. The bacteria behaved like *Flavobacterium*, *Achromobacter* and *Proteus* species. No typical acetic acid bacteria were found. This is hardly surprising, because no mention is made of any arrangements for drainage and aeration.

When fermentation was started at 20° to 25°C., counts showed that bacteria predominated during the first two days, at the end of which only 2% of the organisms were yeasts. The proportions of yeasts and bacteria were reversed after three days. At the end of four days, bacteria again predominated and rose to 62% by the end of the fifth day. Sugar utilisation and acid content of the pulp increased rapidly on the third day and yeasts disappeared rapidly during the two succeeding days. Cultures of the yeasts were capable of forming acetic acid as well as alcohol. *Flavobacterium* and *Achromobacter* predominated at first. The latter were chiefly present on the fifth day.

Similar but more speedy chemical changes occurred during the fermentation initiated at 36°C. At the end of the first day, 78% of the organisms present were yeasts. Fermentable sugars had almost

[30] A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.
[31] S. Hoynak, T. S. Polansky and R. Stone, *Food Research, 6*, 471 (1941).

disappeared. Thereafter bacteria (chiefly *Achromobacter*) predominated. Acidity increased rapidly and rose to a maximum during the second day.

The organisms developed more slowly when fermentation was started at 45°C. Sugar utilisation began to be appreciable on the third day. Acid decreased slowly throughout the fermentation. The bacteria present were chiefly *Achromobacter*.

Discussing the presence of proteolytic bacteria, the authors consider that they are desirable for reducing the quantity of acid present, but detrimental when fermentation proceeds too far.

Underfermentation was apparent in the experiment started at 45°C. The final product was satisfactory in the other two fermentations. The above experiments indicate that the organisms present during fermentation may not be so important as the chemical composition and condition of the beans in producing a satisfactory result.

D. TEMPERATURE AND pH CHANGES

During fermentation of Criollo beans in Ceylon, the temperature rises rapidly, but seldom exceeds 40°C. In Java, higher temperatures for Criollo cacao were observed by Steinmann,[32] who recorded 29° to 35°C. during the first day, 41° to 45°C. on the second day and from 45° to 48°C. on the third day. Vyle[33] states that the ideal range for Venezuelan Criollo is a rise in temperature to between 40° and 46°C. in 40 to 60 hours, with one or possibly two changes from box to box.

In fermenting Forastero cacao in Jamaica, Bainbridge and Davies[34] recorded initial temperatures of 26° to 28°C., end of first day 35° to 40°C., end of second day 40° to 45°C. and thereafter between 45° and 50°C.

Fermentation temperatures are influenced by the size of batch and the amount of aeration permitted by the receptacle used. In Trinidad and Grenada, Knapp[35] determined the temperatures of Forastero beans in boxes containing from 8 cwt. to 30 cwt. The average temperatures noted were 25°C. at the beginning, 30° by the end of the first day, 37° after two days, 47° after three days, 48°

[32] A. Steinmann, *Archif. voor de Cacao*, No. 3, 79 (1928).
[33] L. R. Vyle, in *Cocoa Conference 1949*. The Cocoa, Chocolate and Confectionery Alliance, London, p. 84, 1949.
[34] J. S. Bainbridge and S. H. Davies, *J. Chem. Soc.*, 2209T (1912).
[35] A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.

after four days and 49° during the fifth and sixth days. The rate and range of heat changes observed by Knapp[36] when comparing different types of receptacles used in West Africa are recorded in Table XI.

TABLE XI. GOLD COAST FERMENTATION TEMPERATURES[a]

Length of Fermentation, Days	Heap	Three-tier box, 640 lb.	Basket, 270 lb.	Stem frame, 640 lb.
0	27°C.	27°C.	27°C.	27°C.
1	33°C.	31°C.	29°C.	28°C.
2	43°C.	36°C.	35°C.	36°C.
3	50°C.	44°C.	42°C.	38°C.
4	49°C.	47°C.	46°C.	43°C.
5	49°C.	49°C.	45°C.	41°C.

[a] A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.

Although the optimum temperature for invertase activity is seldom attained during cacao fermentation, any sucrose present in the pulp rapidly disappears.

A temperature of 29°C. is favourable for alcoholic fermentation by wine yeasts in temperate climates. The optimum temperatures for propagation of yeasts in cacao pulp range from 35° to 40°C.[37] The "zymase complex" is destroyed between 40° and 45°C. As the temperature of fermenting heaps of Forastero beans in West Africa usually exceeds 40°C. by the end of the second day, zymase activity beyond this period must be negligible. The temperatures recorded during the ensuing stage of fermentation are higher than those associated with acetic acid production in milder climates. The strains of bacteria which flourish on cacao have evidently adapted themselves to tropical conditions.

The initial pH of the pulp is given by Schwarz[38] (Gold Coast) as 3.8 to 4.0. Hoynak, Polansky and Stone[39] recorded a value of 4.24 for 100 grams of Costa Rican beans diluted with 200 ml. of water and filtered. Whymper[40] determined the pH of skins and pulp and found an initial value of 3.6 followed by a gradual rise. By examining the

[36] A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.
[37] *Ibid.*
[38] L. J. Schwarz, *Cocoa in West Africa*. U. S. Dept. Commerce Bull., Trade Promotion Series No. 68, 1928.
[39] S. Hoynak, T. S. Polansky and R. Stone, *Food Research, 6*, 471 (1941).
[40] R. Whymper, *Chimie et Industrie, 30*, 507 (1933).

pulp from day to day, Schwarz recorded a fall in pH during the first two days, followed by a rise. This has been confirmed by Hoynak, Polansky and Stone in laboratory fermentations started at 20° to 25° and at 36°C. In a fermentation commencing at 45°C., the pH value rose at first, returned to its initial value after two days and thereafter rose gradually.

7. Changes in the Bean

A. LOSS IN WEIGHT

During the fermentation process, the beans, including adhering pulp, lose about 25% of their weight. This is mainly due to drainage of sweatings. Only a small proportion of the loss is accounted for by changes in the chemical composition of the beans. A further loss of 40% is incurred during drying. A final moisture content of between 8% and 6% is desirable. Within this range there is small chance of mould development being established, unless a relative humidity of 82% is exceeded during storage in the tropics.[41]

The change in weight is not equally distributed between the skin, germ and cotyledons of cacao beans. In studying the effects of fermentation on West African Forastero beans, Knapp and Churchman[42] dissected dried fermented beans and compared the weights of the components with those from unfermented beans which had been dried to a similar moisture content. The unfermented beans consisted of germ 0.77%, shell 9.63% and cotyledons 89.60% as against germ 0.70%, shell 10.74% and cotyledons 88.56% from the fermented beans.

B. CHANGES IN THE SEED COAT (SHELL)

When cacao is properly fermented, the appearance of the seed coat is transformed from a soft, white, close-fitting skin to a pale brown, crisp and easily removable shell. In the later stages of fermentation, when the beans have become swollen by absorption of moisture and the shell has been rendered more fragile, great care is necessary when handling. Fracture of the shell exposes the kernels to attack by moulds and insects.

In some countries, it is customary to cover the beans with clay,

[41] A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.
[42] Quoted in A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.

to assist drying. The weight of the shell is considerably increased by this treatment. The practice is becoming less common and is now prohibited in some countries where formerly it was most general.

Beans are sometimes polished to improve their appearance by removing adhering lumps of dried pulp. One way of doing this is to engage natives to dance on the beans.

Normally, the shell gains about 10% of its original weight by fermentation. This gain owes its origin to the property of permeability acquired by the shell on the third and fourth day. The tissues then become saturated with mucilage from the pulp and also retain some of the soluble matter as it diffuses from the interior of the bean. During diffusion, the pH value of the shell is raised.[43]

After drying, brown patches of desiccated bean liquor are visible on the interior surface of the shell.

Macdonald[44] states that there is a slight increase in the fat content of the shell. Some theobromine from the bean liquor is held by the shell.

The origin of vitamin D in sun-dried cacao shell is discussed on p. 99.

C. CHANGES IN THE COTYLEDONS

(1) APPEARANCE

Unfermented beans are oval and somewhat flat. During fermentation the cotyledons absorb moisture and the bean becomes plump. The texture changes from a dense cheesy mass to a crisp structure furrowed by deep fissures. When the shell of dried fermented beans is broken, the cotyledons easily fall apart. The internal structures of unfermented, underfermented and fully fermented Forastero-Amelonado beans are illustrated in Fig. 19.

Pure Criollo beans differ from Forastero and hybrid beans in that they have thinner skins and are less astringent. The most striking visible difference is that their cotyledons contain no purple anthocyanin pigments. Knapp and Hearne[45] recorded the presence of colourless leucoanthocyanins in Criollo cacao. When these compounds are treated with boiling 1% hydrochloric acid solution, an orange colour

[43] A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.
[44] J. A. Macdonald, *6th Ann. Rept. Cacao Research Imp. Coll. Trop. Agr. (Trinidad)*, 1936, 34 (pub. 1937).
[45] A. W. Knapp and J. F. Hearne, *Analyst, 64*, 475 (1939).

is developed. Similar treatment with 5% hydrochloric acid yields a brownish red solution. The presence of pigment in Forastero cacao has assisted in the elucidation of some of the changes set in motion when the seed is killed.

Prior to fermentation, pigmented cells comprise about one-tenth of the entire tissue of purple beans. They are appreciably larger than

A B C

Fig. 19. Forastero-Amelonado cacao beans (×2). (A) unfermented bean, dense cheesy texture, colour slatey grey; (B) underfermented bean, hard tough texture, colour reddish purple, cotyledons not separated; (C) fully fermented bean, hard, tough texture, deeply fissured, colour dark brown. (Original drawing by J. Nicol.)

the surrounding cells and contain neither fat nor starch. Though fairly evenly distributed throughout the cotyledons, they are not present in the radicle. After two to two and a half days' fermentation, the entire tissue of both cotyledons and radicle has become uniformly tinted by the pigment released from the special cells and the formerly almost neutral cell sap (pH = 6.7) now exhibits an acid reaction to litmus. As acidity increases, the purple colour changes to bluish violet and later to red-violet.[46]

(2) THE DEATH OF THE BEAN

Rise in temperature and the formation of alcohol and acetic acid in the pulp are factors which combine to kill first the germ and then

[46] A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.

the cotyledons. Sack[47] observed that the germinating power of cacao beans is destroyed at 43° to 44°C. The germ of Criollo beans is killed in a shorter time and at a rather lower temperature than is necessary for other varieties of cacao. Beans with purple cotyledons are killed during the third day of fermentation. By the fourth day they have acquired the power to absorb moisture and begin to swell. They appear rounder on the fifth day. At the same time, the space between the cotyledons is filled with a brown gummy juice which darkens on exposure to air. Knapp[48] examined the innumerable, minute yellow globules which are present in the juice and found them to be insoluble in water and soluble in alcohol. According to his speculations, these globules are composed of compounds of tannin with theobromine and caffeine.

A programme of research has been started in Trinidad to investigate the nature of enzyme systems operating in fresh cacao beans, with emphasis on those involved in changes in the nitrogenous constituents. It is possible that when the temperature of the beans is well below the final fermentation temperature, the processes of impending germination permit the activation of enzymes and the mobilisation of food reserve materials which play an essential part in fermentation after the bean has been killed.[47a]

(3) ROLE OF OXIDISING ENZYMES

Ciferri[49] identified oxidases, peroxidases, catalase, reductase and philothion (a sulphur-reducing enzyme) and the hydrolysing enzymes invertase, maltase, amylase, dextrinase, emulsin, glycerophosphatase and phytase in fermenting Dominican cacao. In addition to many of the above enzymes, Brill[50] reported the presence of proteolytic enzymes and raffinase in Philippine cacao. The presence of the latter enzyme is surprising in view of the fact that Forsyth[51] has been unable to find raffinose in fresh pulp.

[47] J. Sack in H. H. Smith, *The Fermentation of Cacao*. Bale, Sons & Danielsson, London, 1913.
[47a] C. Y. Shephard, *Cocoa Conference 1951*. The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1951.
[48] A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.
[49] R. Ciferri, *J. Dept. Agr. Puerto Rico, 15*, 223 (1931).
[50] H. Brill, *Philipp. J. Sci., 10*, 123 (1915); *12*, 1 (1917); *Tropical Life, 12*, 5 (1916).
[51] W. G. C. Forsyth, *Nature, 164*, 26 (1949).

Extraneous enzymes make a relatively small contribution to flavour development. On the other hand, the role of oxidising enzymes originating within the bean is highly significant in lowering the astringency to the desired level.

The temperature attained at the time the seed is killed is favourable for action by the oxidising enzymes released. When aerobic conditions are maintained, they pursue their attack for the remainder of the fermentation period and continue to be active almost to the end of the drying process. During oxidation, pigmented cotyledons lose their purple hue and become progressively browner. Cacao oxidase is especially vigorous between 50° and 60°C.[52] It is a water-soluble enzyme, consequently its activity wanes when the moisture content of the substrate falls below 20%, although it is still able to function when the moisture is reduced to 10%. Fickendey[53] found that cacao oxidase could be destroyed at 75°C. Possibly differences in the period of heating and other conditions may account for Loew's statement that cacao peroxidase is capable of survival at 75°C.[54]

Oxidases and peroxidases react readily in neutral or alkaline media and are inhibited when the pH is below 3.0. They are responsible for the browning of vegetable tissues, through their power to oxidise phenolic substances in which the orthodihydroxy catechol group is present. Copper plays an important role in polyphenol oxidase reactions.

In an attempt to distinguish the fermentation changes due to bean enzymes from those caused by microorganisms, Humphries[55] followed the changes in tannin constituents of minced cacao cotyledons during autolysis in air and under water. It appears that autolysis in air causes rapid transformation of oxidisable tannin. A resistant tannin fraction remains which is not attacked by the enzyme responsible for transformation of the oxidisable tannin. There is some evidence that the quantity of resistant tannin in unpigmented beans is comparatively small. The amounts present in pigmented beans varies considerably. It is likely that two different tanninlike substances,

[52] A. Schulte-im-Hofe, in H. H. Smith, *The Fermentation of Cacao.* Bale, Sons & Danielsson, London, 1913.
[53] E. Fickendey, in H. H. Smith, *The Fermentation of Cacao.*
[54] O. Loew, in H. H. Smith, *The Fermentation of Cacao.*
[55] E. C. Humphries, *Biochem. J., 38,* 182 (1944).

possibly leucoanthocyanins, are present in the fraction which resists oxidation.

Autolysis under water results in the disappearance of the tannin originally present by enzymic oxidation and in the build up of additional tannin from some precursor which may be *l*-epicatechin, but this has not been proved. Unless conditions during fermentation are aerobic, an increase instead of a desirable reduction in tannin content may occur.

(4) CHANGES IN COMPOSITION

The pioneer work of Knapp[56] gave an insight into the transformations taking place in the cotyledons of Forastero cacao during the curing process. A notable contribution to the study of the chemistry of cacao fermentation by means of paper chromatograms[57] is discussed on p. 122.

Knapp and Churchman[58] made comparative analyses of dried unfermented and dried fermented cotyledons of West African cacao. Their results are given in Table XII and discussed in the sub-sections below.

Carbohydrates. Whilst Harrison[59] recorded the presence of 1.3% of sucrose in dried unfermented Forastero cacao, a trace in unfermented Calabacillo cacao and none after fermentation, Knapp found no sucrose in unfermented and fermented cotyledons from West Africa. Harrison reported an increase in reducing sugars after fermentation, whereas Knapp recorded a loss of approximately two-thirds of the dextrose originally present. The diminution in starch content observed by Harrison was not confirmed by Knapp, who suggested as a possible explanation, that any diastase present in the bean may be immobilised by the tannins.

Knapp's figures for pectins are astonishingly high. Possibly the method of determination was not sufficiently selective.

Proteins. Knapp's analyses indicate that some breakdown of protein occurs during fermentation. Birch[60] reports that there is a

[56] A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.
[57] W. G. C. Forsyth, *Nature, 164*, 26 (1949).
[58] Quoted in A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.
[59] J. B. Harrison, *Report Agric. Station Brit. Guiana*, 1897; R. Whymper, *Cocoa and Chocolate. Their Chemistry and Manufacture*. 2nd ed., Churchill, London, 1921.
[60] H. F. Birch, *10th Ann. Rept. Cacao Research Imp. Coll. Trop. Agr. (Trinidad)*, 1940, 20 (pub. 1941).

TABLE XII. Composition of the Cotyledons of Dried Unfermented and Fermented West African Cacao Beans[a]

	Unfermented Cotyledons		Fermented Cotyledons	
	Per cent in original	Per cent in dry fat-free material	Per cent in original	Per cent in dry fat-free material
Water	3.65	—	2.13	—
Fat	53.05	—	54.68	—
Ash				
Total	2.63	6.07	2.74	6.34
Water-soluble	1.02	2.36	1.25	2.89
Water-insoluble	1.61	3.72	1.49	3.45
Sand, etc.	0.05	0.12	0.05	0.11
Alkalinity as K_2O	0.51	1.18	0.41	0.95
Chlorides	0.012	0.028	0.014	0.032
Iron (Fe_2O_3)	0.004	0.009	0.007	0.016
Phosphoric Acid (P_2O_5)	0.96	2.22	0.60	1.39
Copper	0.0024	0.0055	0.0028	0.0065
Nitrogen				
Total nitrogen	2.28	5.27	2.16	5.00
Protein nitrogen	1.50	3.46	1.34	3.10
Ammonia nitrogen	0.028	0.065	0.042	0.097
Amide nitrogen	0.188	0.434	0.336	0.778
Theobromine	1.71	3.95	1.42	3.29
Caffeine	0.085	0.196	0.066	0.152
Carbohydrates				
Glucose	0.30	0.69	0.10	0.23
Sucrose	Nil	Nil	Nil	Nil
Starch (Takadiastase method)	6.10	14.09	6.14	14.22
Pectins	2.25	5.20	4.11	9.52
Fibre	2.09	4.83	2.13	4.93
Cellulose	1.92	4.43	1.90	4.39
Pentosans	1.27	2.93	1.21	2.80
Mucilage and Gums	0.38	0.88	1.84	4.26
Tannins				
Tannic acid (Lowenthal's method)	2.24	5.17	1.99	4.61
Cacao-purple and cacao-brown	5.30	12.26	4.16	9.63
Acids				
Acetic (free)	0.014	0.032	0.136	0.315
Oxalic	0.29	0.67	0.30	0.70
Extracts				
Cold water	15.28	35.28	12.29	28.46
Alcohol (85%)	16.80	38.80	9.67	22.39

[a] A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.

continuous decrease of protein nitrogen throughout fermentation of Forastero cacao. Soluble nitrogen (including non-protein nitrogen) increases during the first four days and decreases thereafter. The major changes in protein content take place during a short period immediately following the death of the cotyledons. The loss of soluble nitrogen is continuous throughout. In the early stage, this loss is more than balanced by the rate of increase due to proteolysis. The presence of a proteolytic enzyme which coagulates milk has been noted in commercial cacao by Vilstrup, Bielefeldt and Gottlieb.[61]

Fat. Knapp found no significant difference in the fat content of unfermented and fermented cotyledons. Recent experiments by Humphries[62] indicate that there is a slight increase during the first four days of fermentation, followed by a decline resulting in a small net loss.

Phosphatides. Whilst admitting that there is some evidence of a decrease in lecithin content, Knapp questions Jordan's statement that only 10% of the lecithin originally present in the bean survives fermentation.[63]

Xanthine Bases. The xanthine bases theobromine and caffeine are present in cacao cotyledons. No theophylline, which occurs in tea leaves, has been found. Humphries[64] states that cacao cotyledons lose about 40% of their theobromine during seven days' fermentation. According to Knapp and Wadsworth,[65] the loss of theobromine and caffeine becomes particularly marked on the third day. At this stage, they are dissolved in the bean juice and begin to diffuse into the shell. The transfer proceeds until the percentages of theobromine and caffeine in the bean liquor and shell are almost equal. Traces have also been found in the pulp towards the end of fermentation.

Theobromine (3,7-dimethylxanthine) is a white crystalline powder which sublimes without melting at 290°C. It is a weak base only slightly soluble in cold water and alcohol, and is more readily dissolved on heating. It is soluble in chloroform and tetrachloroethane but sparingly soluble in ether, benzene and petroleum ether. When placed on the tongue, it leaves a bitter taste. Loss of theobromine dur-

[61] V. Vilstrup, J. Bielefeldt and K. Gottlieb, *Gordian, 50,* No. 1185, *27* (1950).
[62] E. C. Humphries, *Trop. Agr. (Trinidad), 21,* 166 (1944).
[63] S. Jordan, *Confectionery Standards,* New York, 1933; A. W. Knapp, *Cacao Fermentation.* Bale, Sons & Curnow, London, 1937.
[64] E. C. Humphries, *Trop. Agr. (Trinidad), 21,* 166 (1944).
[65] A. W. Knapp and R. V. Wadsworth, *J. Soc. Chem. Industry, 43,* 124T (1924).

ing fermentation is partly responsible for the reduction in bitterness of the cotyledons. The quantity remaining suffices to impart a slightly bitter but not unpleasing taste to cacao products. The relatively sweeter taste of Criollo cacao is partly accounted for by a lower theobromine content than that of other varieties.

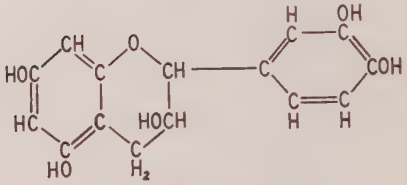
Cacao is the chief natural source of theobromine. It is not known with certainty in what form it occurs in unfermented cacao but there is some evidence that it is loosely bound with tannin and becomes freed during the acetic acid stage of fermentation.[66–68]

The therapeutic effect of theobromine is discussed in Chapter X.

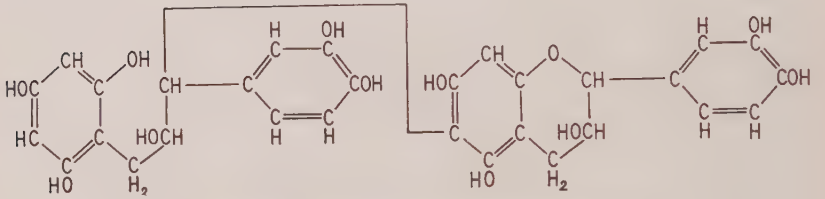
Caffeine (1,3,7-trimethylxanthine) crystallises in lustrous white needles containing one molecule of water which is lost at 100°C. The anhydrous compound sublimes at 180°C. It is a weak base, soluble in 80 parts of cold water or two parts of boiling water. Though insoluble in petroleum ether, it is more readily dissolved than theobromine in other organic solvents and it can be dissolved in hot fat. Like theobromine, it leaves a bitter aftertaste. Unfermented cacao contains about 0.4% of caffeine possibly in combination with catechin.[69] During fermentation, the base is liberated and the bulk of it diffuses through the shell, leaving only about 0.1% in the cotyledons.[70] As the synthetic complex separates into the two components when chromatographed on paper, it has not been possible by this means to confirm whether caffeine occurs as a complex in fresh cacao.[70a]

Tannins and Pigments. At least eleven polyphenolic substances occur in fresh cacao cotyledons. Coloured varieties contain an anthocyanin pigment commonly known as "cacao red." Little or none of this compound survives after efficient fermentation. The presence of two other pigments which undergo rapid transformation has recently been demonstrated by Forsyth.[71] Leucoanthocyanins, catechins, epigallocatechin and gallocatechin have been provisionally identified by him on paper chromatograms.[71a]

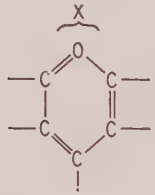
[66] H. Fincke, *Z. Untersuch. Lebensm., 55,* 559 (1928).
[67] H. R. Jensen, *Analyst, 53,* 365 (1928).
[68] A. W. Knapp and R. V. Wadsworth, *J. Soc. Chem. Industry, 43,* 124T (1924).
[69] W. B. Adam, *Analyst, 53,* 369 (1928).
[70] A. W. Knapp, *Cacao Fermentation.* Bale, Sons & Curnow, London, 1937.
[70a] W. G. C. Forsyth, *Nature, 169,* 32 (1952).
[71] W. G. C. Forsyth, *Nature, 164,* 26 (1949).
[71a] W. G. C. Forsyth, *Biochem. J., 51,* 511 (1952).



I. *l*-Epicatechin



II. Possible condensation product of catechin



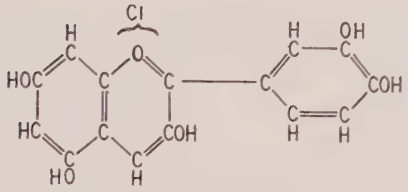
III. Pyrylium structure

Fig. 20. Structural formulas.

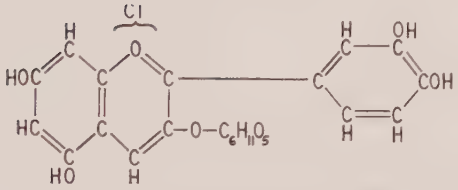
According to Aasted,[72] all the tanninlike substances and pigments found in cacao are derived from the catechin during growth and ripening. Adam, Hardy and Nierenstein[73] isolated the principal catechin from unfermented beans. It is a stereoisomer of catechin ($C_{15}H_{14}O_6$) and was identified by Freudenberg, Cox and Braun[74] as *l*-epicatechin which occurs also in the leaves of tea.

Adam[75] found 0.6–0.8% of *l*-epicatechin in unfermented cacao beans. In properly fermented cacao, all the catechin is changed. Its

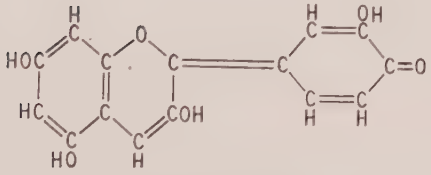
[72] K. Aasted, *Studier over Conchcringsprocessen*. Dyva & Jeppesens, Copenhagen, 1941.
[73] W. B. Adam, F. Hardy and M. Nierenstein, *J. Am. Chem. Soc., 53, 727* (1931).
[74] K. Freudenberg, R. F. B. Cox and E. Braun, *J. Am. Chem. Soc., 54,* 1913 (1932).
[75] W. B. Adam, *Analyst, 53,* 369 (1928).



IV. Cyanidin chloride



V. Cyanidin-3-glycoside



VI. Violet colour base

Fig. 20. Structural formulas (*continued*)

presence in commercial cacao is indicative of incomplete fermentation.

l-Epicatechin crystallises in colourless prisms containing four molecules of water of crystallisation. The anhydrous compound melts at 229°C. Though barely soluble in water and ether and insoluble in petroleum ether and chloroform, it dissolves readily in alcohol and acetone. Its solution is levorotatory.

The structure of *l*-epicatechin is shown in formula No. I. According to Freudenberg and Maitland,[76] a condensation product might have the structure for formula No. II. The formation of such a compound would incur neither loss of water nor oxidation and could therefore proceed in the absence of oxygen. When condensation is

[76] K. Freudenberg and P. Maitland, *Annalen, 510,* 193 (1934).

carried further, in conjunction with oxidation, insoluble brown end products called phlobaphenes are formed. As these compounds are tasteless their formation causes a diminution of astringency.

It is uncertain whether any gallotannins (tannins which give rise to gallic acid or digallic acid and esters of sugars on hydrolysis) occur in cacao. The principal tannin is derived from *l*-epicatechin by condensation. Catechol tannins are incapable of being hydrolysed by acids or enzymes. Nierenstein[77] states that cacao tannin is identical with the tannin occurring in Indian cutch. It is a white colloid with an astringent taste and is soluble in cold water, but insoluble in ether, petroleum ether and chloroform. It is readily oxidised, yielding the dark coloured products commonly called *cacao-brown* and *phlobaphene*. Fincke isolated a coloured intermediate compound which he refers to as cacao-brown parent substance.[78]

During fermentation and drying, only part of the tannin is changed. If it were completely converted into tasteless substances, cacao products would be rather insipid. The purpose of fermentation is to lessen astringency, but not to remove it entirely.

A method for determining the alkali-soluble tannin content of cacao by precipitation with cinchonine sulphate has been described by Jensen.[79]

Duthie[80] determined the proportion of tannin precipitated by cinchonine sulphate from extracts of cacao cotyledons in 40% acetone, and the amount of residual tannin in the filtrate by precipitation with Stiasny's reagent (100 ml. concentrated hydrochloric acid, 100 ml. water and 150 ml. 40% formaldehyde). In the cotyledon dry matter, he found 3.39–4.47% of tannin precipitated by cinchonine sulphate from unfermented and 3.69% from fermented Forastero cotyledon extracts. The corresponding amounts from Criollo cotyledons were 3.26 and 3.59% respectively. The residual tannin amounted to 3.79% in unfermented and 0.39% in fermented Forastero cotyledon extracts and 4.5% in unfermented and 0.64% in fermented Criollo cotyledons. Duthie concluded that the residual tannin was a measure of the catechin present. Hallas[80a] followed the variations in tannin

[77] M. Nierenstein, *Natural Organic Tannins*. Churchill, London, 1934.
[78] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[79] H. R. Jensen, *Analyst, 53*, 365 (1928).
[80] D. W. Duthie, *Analyst, 63*, 27 (1938).
[80a] C. A. Hallas, *Unpublished data*. British Food Manufacturing Industries Research Association.

content during fermentation by determining the amounts precipitated by cinchonine sulphate from cold decinormal hydrochloric acid extracts of air-dried cacao beans. His results, given in Table XIII,

TABLE XIII. Tannins Extracted by Cold *N*/10 Hydrochloric Acid from Air-dried Defatted Cacao Beans at Different Stages of Fermentation[a]

Description of bean	Soluble tannin, %	
Criollo		
Unfermented Trinidad	12.1	
Unfermented Trinidad	15.5	
Unfermented Venezuelan	13.2	
Unfermented, origin unknown	14.2	
Fermented Tobago	1.8	
Fermented South American	8.4	
Forastero		
Unfermented (from pod) West African	20.3	
Unfermented West African	17.2	
Poorly fermented West African	13.3	
Well-fermented West African	5.4	
Well-fermented Trinidad	4.7	
Well-fermented Grenada	4.9	
Forastero, West African		
Days fermented	Series A	Series B
0	19.1	19.3
1	15.7	15.9
2	15.2	14.6
3	15.0	13.4
4	14.1	10.5
5	13.0	7.5
6	8.6	6.5

[a] C. A. Hallas, *Unpublished data*, British Food Manufacturing Industries Research Association.

demonstrate that there is a progressive decline in the percentage of dilute acid-soluble tannins throughout fermentation.

The most important pigment present in the coloured cotyledons of unfermented cacao beans is frequently spoken of as *cacao-red*. Knapp[81] preferred the name *cacao-purple* to distinguish it from the red-brown condensation products of catechin or tannin. During fermentation, the intensity of colour diminishes until the third day, when

[81] A. W. Knapp, *Cacao Fermentation*. Bale, Sons & Curnow, London, 1937.

the cotyledons begin to turn brown and become progressively darker. Browning continues when the beans are drying. According to Fincke[81a] the end product is identical with the condensation products of catechin and tannin, namely cacao brown.

The harsh, astringent taste of poorly fermented cacao is to some extent associated with the survival of a proportion of the pigment.

Hieduschka and Bienert[82] obtained amounts up to 2% of cacao red from commercial Arriba cacao. As this product is not fully fermented it is not surprising that so much unaltered pigment was present. According to Knapp and Churchman[83] there is a transfer of part of the pigment and its oxidation product to the shell during fermentation.

Robinson and co-workers[84] established that cacao red is the anthocyanin pigment cyanidin 3-glycoside. Its presence in the cotyledons of cacao provides an example of anthocyanin formation without direct photosynthesis. Red and blue pigments of this class are usually located in the parts of plants which are exposed to light. It is probable that young cacao leaves, flowers and purple varieties of pods are coloured by the same pigment.

The structure of the anthocyanin colouring matters of plants has been elucidated by Robinson, Karrer and their co-workers. Most of the important anthocyanins have now been synthesised in the laboratory.[85]

These compounds all contain the pyrylium structure (formula III) linked with a benzene ring to form a benzopyrylium group. The bracket over the structural formula indicates the electrovalency of salts where charged ions are bound by electrostatic attraction.

The anthocyanins are glycosides of anthocyanidins. Cyanidin chloride (formula IV) is the chloride of the anthocyanidin from which cacao-red is derived. The structure of the latter is shown by formula V. It will be seen that it is related to that of *l*-epicatechin (formula I) which likewise gives rise to the condensation product cacao-brown.

Cyanidin 3-glycoside is a crystalline substance, somewhat soluble in water and readily soluble in methyl and ethyl alcohol, but in-

[81a] H. Fincke, *Z. Untersuch. Lebensm., 55,* 559 (1928).
[82] A. Hieduschka and B. Bienert, *J. prakt. Chem., 119,* 199 (1928).
[83] A. W. Knapp and A. Churchman, *J. Soc. Chem. Ind., 56, 29* (1937).
[84] W. J. C. Lawrence, J. R. Price, G. M. Robinson and R. Robinson, *Biochem. J., 32,* 1661 (1938).
[85] R. Robinson, *Endeavour, 1,* 92 (1942).

soluble in ether, petroleum ether, chloroform, and benzene. It appears red by transmitted light and exhibits a fine bronze lustre. In neutral aqueous solution it is purple. By the action of weak alkali (sodium acetate) it is converted into a violet colour base (formula VI). When strongly alkaline, it is green. The colour becomes pink in acid solution, but on dilution, a colourless pseudo base is formed. These changes at different pH levels provide an explanation of the alterations in the colour of the cotyledons during fermentation.

Hallas[86] determined the total cyanidin (derived from antho-

TABLE XIV. Comparison of Amount of "Total Cyanidin" and Cyanin in Cacao Beans at Different Stages of Fermentation[a]

Description of bean	Colour of nib	Total cyanidin as cyanidin chloride, approx. %		Total cyanin as cyanidin chloride, approx. %	
Criollo					
Unfermented Trinidad	White	0.60			
Unfermented Trinidad	Pale brown	0.58			
Unfermented Venezuelan	Pale brown	0.46			
Unfermented, origin unknown	White	0.58			
Fermented Tobago	Brown	0.48			
Fermented S. American	Brown	0.75			
Forastero					
Unfermented W. African	Bluish grey	1.23		0.53	
Unfermented W. African	Bluish grey	1.12		0.42	
Poorly fermented W. African	Purple	0.92		0.06	
Well fermented W. African	Brown	0.81		0.01	
Well fermented Trinidad	Brown	0.81		0.01	
Well fermented Grenada	Brown	0.81		0.01	
Forastero, W. African		Series A	Series B	Series A	Series B
Days fermented					
0	Bluish grey	1.14	1.16	0.53	0.59
1	Slightly more purple	0.94	0.96	0.27	0.29
2	Purple	0.89	1.00	0.15	0.38
3	Browner	0.83	0.79	0.07	0.06
4	Browner	0.83	0.79	0.05	0.02
5	Browner	0.79	0.77	0.03	0.02
6	Brown	0.79	0.77	0.025	0.02

[a] C. A. Hallas, *Unpublished data*. British Food Manufacturing Industries Research Association.

[86] C. A. Hallas, *Unpublished data*. British Food Manufacturing Industries Research Association.

cyanins and leucoanthocyanins) and the cyanin (derived from anthocyanins) in air-dried defatted Forastero beans and the total cyanidin in air-dried Criollo beans at successive stages of fermentation by optical density measurements, using cyanidin chloride as a standard of reference. A synopsis of the methods used appears in Chapter XI. The results are compared in Table XIV, where it is shown that the cyanin has practically disappeared after two days.

A new approach to the study of fermentation changes has been opened by means of chromatographic analysis. Karrer and Strong[87] succeeded in overcoming the difficulties of separation of anthocyanins on a Tswett column. More recently, Bate-Smith[88] has given details for the separation of the anthocyanins derived from the petals of *Dahlia variabilis* by means of paper chromatograms. Using a partition solution of butanol-acetic acid-water mixture in the proportions 40:50:10, he measured their R_F values by locating spots in visible and ultraviolet light and also by development with ammonia or ammoniacal silver nitrate. Catechin will reduce ammoniacal silver nitrate in the cold. The anthocyanidin obtained from the monoglycoside is described as mauve in air and grey-blue in ammonia vapour. Its R_F value is 0.31 in 1% hydrochloric acid. A further improvement in technique was achieved by the use of phenol-1% acetic acid in place of the butanol mixture. Bate-Smith states that aglycones, especially cyanidin are unstable unless sufficient hydrochloric acid is present and recommends 2 *N* hydrochloric acid-butanol for satisfactory results. Fission products of anthocyanins examined in ultraviolet light or when developed with ammoniacal silver nitrate show numerous spots which he attributes to fission products of the pyrylium ring.[89]

The following procedure was used by Forsyth[90,90a] for studying the tannins and pigments in fermenting cacao.

One bean was killed by heating at 100°C. for two minutes and extracted with 1% hydrochloric acid. After allowing the partition solvent (amyl alcohol 4, acetic acid 1, water 5 parts) to run for 12–15 hours, the papers were examined in visible and ultraviolet light while still moist and when dry. They were then sprayed with saturated sodium carbonate, dried and re-examined in visible and

[87] P. Karrer and F. M. Strong, *Helv. Chim. Acta, 19,* 25 (1936).
[88] E. C. Bate-Smith, *Nature, 161,* 835 (1948).
[89] E. C. Bate-Smith, *Biochem. J., 43,* xlix (1948).
[90] W. G. C. Forsyth, *Nature, 164,* 26 (1949).
[90a] W. G. C. Forsyth, *Biochem. J., 51,* 511 (1952).

ultraviolet light. In all Forastero cacao examined, five well-defined spots were invariably obtained and other faint spots were observed. The principal spots stand out clearly from a brown background (probably tannin) after spraying with sodium carbonate. Their R_F values vary to some extent, but the spots can be recognised by their colour reactions. The individual spots were cut out, re-extracted with 1% hydrochloric acid, and examined by the method of Robinson and Robinson.[91]

Spot 1. A faint pink extract. A diglycoside of cyanidin and a leucoanthocyanin (aglycone also cyanidin) were present. R_F 0.00.

Spot 2. A deep red extract. A pentoside, yielding cyanidin on hydrolysis R_F 0.08.

Spot 3. A deep red extract. Cyanidin 3-glycoside. R_F 0.16.

Spot 4. A colourless extract yielding cyanidin on boiling with concentrated hydrochloric acid. A leucoanthocyanin. R_F 0.29.

Spot 5. A colourless extract. Bright orange with alkali, green with ferric chloride and giving a black spot when sprayed with ammoniacal silver nitrate. Its R_F value, 0.42, is identical with that of *l*-epicatechin.

In every case, the aglycone was cyanidin.

Cyanidin monoglycoside was not eliminated until the 90th hour, whereas the other two pigments had disappeared by the 45th hour. None of the above constituents could be detected in fermented sun-dried beans.

The two leucoanthocyanins detected in Forastero cacao were present in much larger quantities in Criollo cacao, but no anthocyanins were found.

In subsequent work, by chromatographing anthocyanin concentrates on cellulose columns, two anthocyanins were identified, one of which contained glucose and the other glucose and arabinose. There was a trace of a third pigment with the properties of a cyanidin diglycoside.

Free Acids. The quantity of acetic acid retained by Forastero cotyledons depends on the length of fermentation and the method of drying. In Criollo beans it is often negligible because fermentation is stopped before any significant acetic acid development has taken place. The values for acetic acid given in Table XII show that the increase in acidity, due to diffusion of acetic acid generated in the pulp, is quite considerable in the cotyledons of Forastero cacao. The oxalic acid content is practically unchanged.

[91] G. M. and R. Robinson, *Biochem. J.*, *25*, 1687 (1931); *26*, 1647 (1932); *27*, 206 (1933).

Inorganic Constituents. As a result of diffusion, the mineral content of the cotyledons is raised. The gain is therefore more appreciable in the water-soluble fraction. According to Knapp (Table XII) there is a loss during fermentation of about one-third of the phosphate.

Flavour and Aroma. The two most important processes concerned with the development of flavour and aroma in cacao products are curing and roasting. If the correct balance between bitter and astringent components has not been achieved during fermentation, it cannot later be satisfactorily rectified. It has been noted that flavour may be adversely affected by the presence of underripe and overripe beans, lack of aeration and drainage, infiltration by moulds and contamination by smoke during drying.

It has been suggested that the desirable chocolate odour may originate from some constituent of the pulp and that certain of the organisms present are responsible for its development. In support of this theory, Briton-Jones[92] mentions that *Willia anomala* products pleasant-smelling esters.

The conclusion reached by Forsyth, after following the changes in the five main polyphenol components of cacao cotyledons during fermentation by means of chromatograms, is that the conversion of cyanidin compounds may possibly exert a greater influence than tannin oxidation on the flavour and aroma of cacao products. The main transformation appears to be the conversion of cyanidin compounds to leucoanthocyanidins. It has been shown that part of the catechin lost by exudation from the cotyledons is to some extent oxidised in the testa. Under the anaerobic conditions of fermentation, the oxidases do not act on the catechin remaining in the cotyledons until the drying period.[92a]

Preliminary experiments on aseptic methods of fermentation at the Colonial Microbiological Institute, Trinidad, indicate that when conditions allow initial oxidation even at the optimum pH, the final product is lacking in chocolate aroma. Beans fermented under partial or completely anaerobic conditions at pH 6.5–7 do not give an acceptable product. When the pH is adjusted to 5–5.6, the flavour is more promising. The best results were obtained by fermenting sterile

[92] H. R. Briton-Jones, *The Diseases and Curing of Cacao.* Macmillan, London, 1934.

[92a] W. G. C. Forsyth, *Biochem. J., 51,* 516 (1952).

beans in anaerobic jars packed with cellulose pulp soaked with buffer solution. These findings are contrary to the previously accepted opinion that oxidation of the cotyledons commences immediately the beans are killed. It now appears likely that oxygen introduced by turning the beans during commercial fermentation is almost entirely utilised by the organisms present.[92b]

The aroma of cured cacao, though slightly reminiscent of vinegar, is subtly fragrant, but it differs from the pronounced aroma of roasted cacao, attributed by Bainbridge and Davies[93] to the presence of a mixture of essential oils, the main constituent of which is *d*-linalool.

Samples of commercial cacao beans may be judged for flavour by roasting a few handfuls in a sample roaster. The flavour developed in this way is similar to that produced by roasting on the commercial scale. On the other hand, beans fermented in small lots, as for example in tests on selections, often fail to develop the full flavour of commercially fermented beans. This lack of reproducibility in small-scale fermentations makes quality tests on new clones somewhat uncertain, but some measure of success has been obtained at the West African Cacao Research Institute[94] when 10 mls. of pulp from a large-scale fermentation are mixed with two grams of dextrose and added to the contents of a single pod. The mixture is then incubated at an initial temperature of 43°C. and controlled between 43°C. and 49°C. for six days. The mass is turned each day and continually aerated at a rate of three litres per day. The best batches contained 46% of fully fermented and 54% of slightly underfermented beans. The colour of the latter was satisfactory, but the cotyledons were not separated. At the American Cacao Center,[95] it has been proposed that beans from trial plots in Costa Rica should be washed to remove the pulp, then dried and dispatched to the United States for further processing. It is possible that this divergence from the natural method of curing may affect the reproducibility and quality when comparing beans from small lots with those from fermentations on the commercial scale.

Post-fermentation has been proposed as a remedy for improving the quality of insufficiently fermented cacao, but it has not become an established practice owing to the extra cost involved.

[92b] W. G. C. Forsyth and J. E. Rombouts, *Cocoa Conference, 1951.* The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1951.
[93] J. S. Bainbridge and S. R. Davies, *J. Chem. Soc.*, 2209T (1912).
[94] Anon., *Ann. Rept. West African Cacao Research Institute 1948–49*, Tafo, Gold Coast, 1950.
[95] G. F. Bowman, *Cacao Information Bull., 1,* No. 20, 1 (1950).

Forsyth[96] envisages the usefulness of paper partition chromatography as a means of following the changes during pure culture and "sterile" fermentations of cacao beans.

8. Alternative Methods of Curing

Fickendey[97] was one of the first investigators who attempted to cure cacao by other means than fermentation. With the aim of killing the seed, but preserving the oxidising enzymes, he soaked beans in alcohol for ten minutes and exposed them to alcohol vapour for four or five days. They were then quickly washed in water and dried. In another experiment, he killed the beans by freezing. Although beans treated by either of these methods were said to have the characteristic flavour of chocolate, they lacked the aroma.

Perrot[98] used potassium carbonate to remove the pulp and then killed the beans by steam sterilisation. The enzymes did not survive when the temperature was sufficiently high to kill the beans.

Stevens[99] claimed that exposure to 40° to 60°C. for several days gave rise to a product which was superior to fermented cacao in both appearance and flavour. Knapp and Dade[100] were unable to confirm this.

Hardy[101] recommended the use of acetic acid or citric acid to kill the cacao beans.

The removal of pulp presents some difficulty. Briton-Jones[102] found that it could be facilitated by dusting the beans in quicklime before washing. Preuss[103] succeeded in removing the pulp by heating the beans to 45°C., fermenting for one day and washing with warm water. The beans were then partially dried and oxidised in stagnant air for two or three day at 45° to 60°C. Drying was then completed in

[96] W. G. C. Forsyth, *Nature, 164,* 26 (1949).
[97] E. Fickendey, in H. H. Smith, *The Fermentation of Cacao.* Bale, Sons & Danielsson, London, 1913.
[98] E. Perrot, *C.R. Acad. Sci., 156,* 1394 (1913); A. W. Knapp, *Cacao Fermentation.* Bale, Sons & Curnow, London, 1937.
[99] F. L. Stevens, *Bull. Dept. Agr. Trinidad, 21,* 27 (1925).
[100] A. W. Knapp, *Cacao Fermentation.* Bale, Sons & Curnow, London, 1937.
[101] F. L. Hardy, *Trop. Agr. (Trinidad), 3,* 232 (1926).
[102] H. R. Briton-Jones, *The Diseases and Curing of Cacao.* Macmillan, London, 1934.
[103] P. Preuss, *Tropenpflanzer, 29,* 343 (1926).

about 12 hours. Muller,[104] who worked on similar lines, invented a drying shed, patented as the "Brumutro," for his process.

It is doubtful whether any of the above processes can give rise to a commodity which will compare satisfactorily with well-fermented cacao. Apart from the disadvantage due to higher overhead costs or the necessity for adequate supply of water to remove the pulp, it is becoming apparent, as the gradual elucidation of fermentation transformations proceeds, that no single artificial treatment can serve entirely as a substitute for the complex changes which take place under natural conditions.

[104] B. Muller, British Patent 329,015: "An improved process for and apparatus for use in the fermentation of cocoa beans." February 8, 1929.

CHAPTER VII

MANUFACTURE OF CHOCOLATE LIQUOR

1. Grading and Storage

It is inevitable, especially when cacao is fermented by the more primitive methods, that there will be a certain proportion of defective, that is to say mouldy, weevily, flat and germinated beans, besides others which are unfermented or only partially fermented. It is therefore necessary to grade the various lots by inspection of an average sample. The inspection and grading are undertaken by the appropriate Agricultural Department.

In 1938, the Office International du Cacao et du Chocolat recommended a grading system, by means of which points were given or subtracted for dimensions of beans, colour and odour and absence of imperfect beans. In the case of West African cacao, the standards adopted are 22 mm. for length and 8 mm. for thickness and a sample of 300 beans must weigh at least eleven ounces, otherwise it is described as *light* cacao.

In Nigeria, cacao is graded according to the percentage, by count, of defective (mouldy, weevily, decayed, flat and/or germinating) and slatey (unfermented and/or insufficiently fermented) beans. All cacao must be thoroughly dry, free from foreign matter and from smoky, velvety or black beans. In grades II–IV the number of mouldy beans is restricted to 5%. For the 1947/48 crop, the grading was as follows:

Grade I. Less than 5% defective and 5% slatey beans.
Grade II. Less than 10% defective and 10% slatey beans.
Grade III. Less than 10% defective and 20% slatey beans.
Grade IV. Less than 10% defective. No limit to slatey beans.

Only Grade I and Grade II beans are now accepted by the Nigerian Marketing Board.

The standards for cacao grown in the French Empire and mandated territory are somewhat similar. High grade cacao is the same as

Grade I in Nigeria and in a general grade a maximum of 10% defective (of which not more than 5% are mouldy) and 10% unfermented beans are allowed. In low grade cacao the limits are 15% of defective, including not more than 10% of mouldy beans, and 20% unfermented beans. Inspection is made at the port of shipment and the grading is valid for four months, after which the beans should be reinspected.

After grading, the cacao beans are weighed into strong clean jute sacks, which are then sewn up. The weight of the beans per sack varies according to the custom of the country of origin, from 196 pounds in the West Indies to 1 cwt. in Ceylon and Venezuela. The sacks are collected and transported as soon as possible to the port, whence they should be shipped without delay, firstly because the tropical climate is too humid for prolonged storage and secondly to minimise the danger of attack by insects.

During the second world war, when it was realised that stocks might have to be held for unusually long periods, owing to the uncertainty of shipping, the Agricultural Department of Nigeria insisted on the following conditions for storage:[1]

(a) Rainproof, light and airy stores with a good concrete floor.

(b) All stores and dunnage to be thoroughly cleaned and whitewashed before commencement of the season.

(c) Stacks of tightly packed bags of cacao to be as large as possible and separated from walls by three-foot alleyways.

(d) Precautions to be taken against infestation: Dishes of carbolic soap solution placed at six-inch intervals on the floor and two layers of pissava strands coated fortnightly with "ATE" (made by boiling three parts of the coagulated latex of *Carpodinus hirsuta* with two parts of shea butter) hung round each stack. The stacks had to be brushed every day to remove any moth cocoons.

More recent recommendations include spraying all internal surfaces of emptied premises with DDT or BHC in aqueous suspension every six months. The use of the Todd Insecticidal Fog Applicator will help to reduce infestation in loaded stores and a layer of DDT, BHC or an inert dust may be laid round the base of the walls. Fumigation should preferably be with methyl bromide. In Southern Nigeria it is suggested that there should be co-operation with the tobacco

[1] A. H. Young, Cocoa Storage in Nigeria. *Report and Proceedings of the Cocoa Research Conference 1945.* His Majesty's Stationery Office, London, 1945.

industry on the joint problem of overcoming *Lasioderma* infestation in tobacco and cacao.[1a]

2. Transport

In many cacao-producing countries, the construction of new roads and railways has revolutionised transport, but in less accessible districts the means of conveying the beans are both primitive and picturesque. In parts of West Africa remote from roads, cacao is still carried from outlying farms to the grading stations by head load or trundled over the ground in barrels. In Bahia nearly 90% of the crop is transported over new and improved roads and the remainder is conveyed by mules, rail, canoes and motor launches. Shipment has been greatly facilitated especially in West Africa by the construction of new harbours. In places where cacao has to be transferred from the shore to cargo boats by means of surf boats, the sacks are protected with tarpaulin to prevent damage by sea water during loading. When the beans are kept dry, the chances of infestation being communicated by other cargoes is minimized. If infestation has taken place, it will not be apparent at once and outbreaks may occur when the bags are stored for long periods in dockside warehouses in the country of destination. Fumigation, the use of sticky bands or impregnation of the sacks with DDT are recommended for dealing with trouble at this stage.

3. Factory Precautions

Between the base of equipment and the floor, there should be sufficient space to provide easy access for cleaning. Similarly, machines should not be erected too close to the walls, as deposits of dust containing food particles are suitable breeding grounds for moths. Pipes and cables in contact with the walls cannot easily be kept clean. Tongued and grooved partitions invite the accumulation of dust whereas plywood presents a surface which avoids this objectionable feature. The use of metal trays which can be sterilised is recommended, together with metal racks on which they may be stacked. Wooden tables and trolleys are often a source of contamination, through pro-

[1a] *Insect Infestation of Stored Food Products in Nigeria.* Her Majesty's Stationery Office, London, 1952.

viding hiding places for pests. These should be replaced by specially designed metal trolleys.[2,3]

In chocolate factories where a large amount of sugar is stored, it should be distributed over more than one storage area to minimize fire hazard. Stores should be dry, well ventilated and free from sugar dust.[4] To minimize fire and explosion hazards, pulverising should be done in a separate building, constructed of fireproof materials, or else at the top of the main building. All ducts, pipes, etc., should be of metal and be dust-tight; motors, switches, etc., should be explosion-proof types. Metal and electrical equipment should be earthed and all sugar delivered to pulverizers should pass over self-cleaning magnetic separators.[5]

4. Outline of Processing for Cocoa and Chocolate Manufacture

In the initial stages, the processes of manufacture are essentially the same for cocoa and chocolate. The beans are cleaned, roasted and shelled and the kernels are then reduced by grinding to cacao mass or chocolate liquor. Cocoa powder is obtained by pulverising the cake which remains when part of the fat (cocoa butter) is removed from the liquor by pressure. Chocolate is made by mixing chocolate liquor, sugar and cocoa butter and subjecting the product to various refining processes. The accompanying flow sheet (Fig. 21) indicates the usual sequence of processes employed, but it should be noted that germ separation is an optional refinement and that not all cocoa powders are alkalised. In some factories vacuum drying replaces roasting and in the later stages of chocolate manufacture the functions of refining and conching may be combined in a single machine. The manufacture of cocoa and chocolate is fully described by Williams.[5a] For a more concise account, an article by Schoen[5b] may be consulted.

[2] *Factory Fittings, Mountings, Appliances and Furnishings with Regard to the Control of Moth Pests.* 2nd ed., British Food Manufacturing Industries Research Association, London, 1947.

[3] *Machinery Design and the Control of the Moth Pests in Factories.* 2nd ed., British Food Manufacturing Industries Research Association, London, 1947.

[4] R. P. Alden, *Manufacturing Confectioner, 26*, No. 11, 60 (1946).

[5] *U. S. Dept. of Labor Bulletin 562.* Safety Codes for Prevention of Dust Explosions. Safety Code for Pulverising Systems for Sugar and Cocoa.

[5a] C. T. Williams, *Chocolate and Confectionery*, 2nd ed. Leonard Hill, London, 1953.

[5b] M. Schoen in M. B. Jacobs, *The Chemistry and Technology of Food and Food Products*, 2nd ed., Vol. III. Interscience, New York-London, 1951.

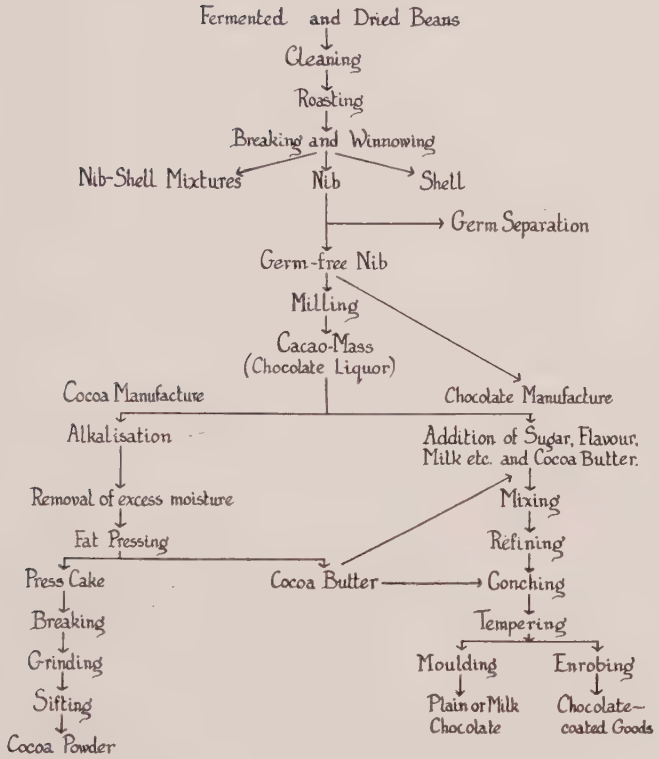


Fig. 21. Cocoa and chocolate factory flow sheet.

5. Cleaning

The hazards of moth infestation during processing are minimised when sacks of beans are stacked in a building apart from the main factory. A light airy shed with all-metal fittings is suitable for storage.

Before use, beans are cleaned and rebagged in clean sacks. The original sacks can be made ready for re-use by stoving them at 60°C. to kill any grubs. It is desirable to clean the beans in the storehouse, so that they enter the factory in good condition.

Bean cleaners are designed to remove adhering earth, broken beans, pieces of jute from the bags and other foreign material such as stones, nails, straw and fragments of clothing.

On entering the machine from a hopper, the beans pass through

screens of different meshes which are mechanically brushed and agitated. By this means fragments and clusters of beans are segregated. A current of air aspirates dust. The cleaned beans are delivered on an inspection band at the rate of about one ton per hour, and any foreign bodies which have passed through the machine are picked out by hand. As an extra precaution, the beans may be passed over an electromagnet, to free them from pieces of metal such as nails which could cause damage to machines as well as being injurious to health.

According to Bywaters[6] about 0.35% of foreign material and 1.15% of broken and double beans are removed by cleaning. Such beans are not included in the manufacture of high class goods, but they are sometimes utilised in cheap lines.

The bean cleaner also acts as a grading machine, for the emerging beans are roughly sorted according to size. When the different grades are roasted in separate charges, heat penetration is more uniform.

6. Roasting

Roasting is an operation which demands skill and experience. Its purpose is to develop flavour and aroma and to render the cotyledons (nibs) sufficiently plastic for easy grinding. The seed coat is loosened by roasting and thus transformed into a readily removable shell.

A. TIME AND TEMPERATURE

No rigid rules can be laid down for time and temperature of roasting as these factors vary with the size and type of beans, their moisture content, the kind of equipment used and according to whether the ultimate product is cocoa, chocolate or milk chocolate. The heat is so regulated that it penetrates to the centre of the beans without causing the outer tissues to acquire a burnt flavour. For guidance of the operator, roasters are equipped with instruments for recording temperature and loss in weight, and a sampling device enables the beans to be inspected for colour, crispness of break and aroma.

The period of roasting may vary from 15 minutes to two hours, or the process may be continuous.

Heating by gas or coke is more usual than electricity, which is said to make the air too dry. When roasting is too vigorous, excessive

[6] H. W. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture*. Churchill, London, 1930.

darkening and a decrease in available protein will result.[7] Flavour is somewhat crude and underdeveloped when the beans are insufficiently roasted. A gentle roast is appropriate for chocolate. More vigorous treatment is required for cocoa. Jensen[8] states that temperatures above 120°C. (248°F.) are excessive for chocolate. Tresper Clarke[9] recommends roasting at 104° to 121°C. (220–250°F.) as suitable for cocoa. He points out that "full roast" in Europe is equivalent to medium or three-quarters roast in America where "full roast" ranges about 121° to 134°C. (250° to 280°F.).

A low roast at 95–110°C. (203–230°F.) is sufficient to bring out the flavour of Criollo beans. For this reason, it is better to roast them separately, and blend afterwards.

B. TYPES OF ROASTERS

An old form of roaster capable of roasting a charge of 4–5 cwts. in 65–75 minutes at 110–130°C. consists of a rotating cylinder heated by gas jets. Such a machine cannot achieve the aim of uniform treatment for each individual bean.

Roasting by means of hot air offers the advantages of greater uniformity and rapidity. The Barth Sirocco roaster of German construction and machines of similar design are popular in Europe. The Sirocco is operated on the following lines:

The charge is fed from a hopper into a revolving metal ball enclosed in an outer shell and is subjected to a hot air blast. The air may be heated by coke, oil or pressure gas. It is possible to roast a batch in 15–30 minutes. With a charge of 250 kilograms, the roast is accomplished in 20 minutes at 130°C. (gas 20 cu. m./hr.) or in half an hour at 100–110°C. (gas 15 cu. m./hr.). When the machine is stopped, the contents are dropped into a perforated tray and cooling is effected in 2–3 minutes by a current of air. Further heat changes are thereby arrested.[10,11]

[7] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate, Confectionery and Cocoa.* Churchill, London, 1931.
[8] *Ibid.*
[9] W. Tresper Clarke, *Chocolate and Cocoa,* in *Encyclopedia of Chemical Technology, Vol. III,* p. 898. Interscience Encyclopedia Inc., New York, 1949.
[10] *British Intelligence Objectives Subcommittee Report No. 1077.* (German Chocolate, Cocoa and Confectionery Layout.) His Majesty's Stationery Office, London, 1946.
[11] *British Intelligence Objectives Subcommittee Report No. 1115.* (German Chocolate Machinery.) His Majesty's Stationery Office, London, 1946.

Continuous roasting is effected by allowing a blast of hot air to rise from the base of a cylindrical shell. Some machines are thirty feet high. The charge then enters from an upper floor and as the beans travel slowly downwards by a circuitous path, they are met by the hot

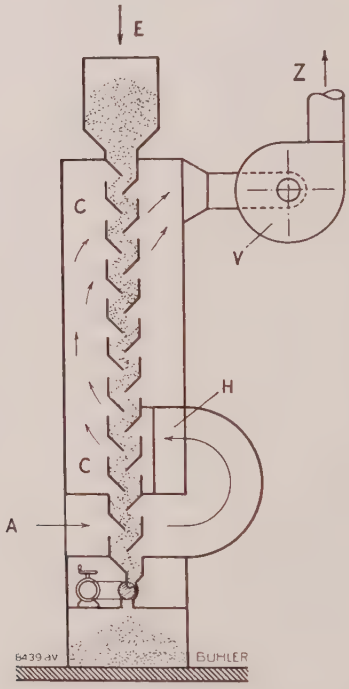


Fig. 22. Diagrammatic illustration of continuous roaster, Buhler type STK. The beans enter the roaster at E and cascade down to the feedplate. The heater H heats the air which is forced through the moving beans by the fan V. Heat and airflow can be regulated and kept constant. Once the temperature has been fixed and the feed set, an unlimited number of beans can be treated. Every individual bean receives uniform treatment. (By permission of Gebruder Buhler, Switzerland.)

air current which is directed so that it plays uniformly over the entire surface. One of the advantages of this type of roaster is that it reduces bean breakage to a minimum. A diagram of a more compact machine, the Buhler STK Roaster, is shown in Fig. 22.

On all types of roasters, suitable arrangements are made for conducting away or condensing the vapours which are given off.

In the process described as "mass roasting," the beans are subjected to a preliminary light roast and the shell is removed by winnowing. After grinding the nibs, the resulting chocolate liquor is heated by high pressure steam. The treatment is designed to improve uniformity, but the flavour developed is less well pronounced.

Tresper Clarke[12] mentions several modern evolutions in roasting technique, some of which are still in the experimental stage.

C. CHANGES DURING ROASTING

The loss in weight incurred by roasting is mainly accounted for by evaporation of moisture and acetic acid. Jensen[13] demonstrated that a small quantity of fat is volatilised. The shell absorbs a trifling quantity of fat from the cotyledons.

Bywaters[14] places the overall loss through roasting at 6%, of which 4.6% is given up by the cotyledons and 1.4% by the shell. Fincke[15] states that there is a loss of 4–6% when processing for cocoa and 3–4% for chocolate. The residual moisture content of beans on discharge from the roaster is 2.5 to 5%, depending on the degree of roasting.

The colour of the cotyledons deepens to a rich brown and their taste becomes less acrid. These changes are to some extent consequent on the conversion of tannin constituents to dark coloured tasteless phlobaphenes. Jensen[16] refers to the formation of pleasant aromatic substances and removal of astringent and other unpalatable constituents such as pungent organic bases and products of protein decomposition but gives no quantitative data. Bainbridge and Davies[17] obtained 24 grams of essential oil of cacao from 2000 kilograms of lightly roasted Arriba cacao. More than 50% of the whole oil was

[12] W. Tresper Clarke, *Chocolate and Cocoa*, in *Encyclopedia of Chemical Technology, Vol. III*, p. 898. Interscience Encyclopedia Inc., New York, 1949.
[13] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate, Confectionery and Cocoa*. Churchill, London, 1931.
[14] H. W. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture*. Churchill, London, 1930.
[15] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[16] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate, Confectionery and Cocoa*. Churchill, London, 1931.
[17] J. S. Bainbridge and S. R. Davies, *J. Chem. Soc.*, 2209T (1912).

TABLE XV. CHANGES IN CACAO NIB COMPOSITION DUE TO ROASTING

Kind of beans	Not specified[a]		Accra[b]		Grenada[b]		St. Thomé[c]		Trinidad	
	Raw, %	Medium roast, %	Raw, %	Roast, %	Raw, %	Roast, %	Raw, %	Low roast, %	Raw, %	Low roast, %
Moisture	5.13	3.71	4.9	3.2	4.8	2.9	4.70	3.46	5.58	3.89
Fat	54.22	53.63	53.9	55.1	53.4	54.4	53.76	53.26	50.64	50.64
Ash	1.46	1.51	2.24	2.50	2.03	2.23	2.52	2.64	2.60	2.86
Starch	7.31	7.70	—	—	—	—	8.89	8.94	9.55	9.29
Protein	11.99	12.01	12.88	13.00	12.16	12.13	11.18	11.43	11.62	11.00
Theobromine	1.09	1.06	1.36	1.33	1.07	0.75	0.89	0.99	0.74	0.64
Caffeine	0.44	0.43	—	—	—	—	0.18	0.22	0.38	0.34

[a] A. L. and K. B. Winton, *Structure and Composition of Foods. Vol. IV*, Wiley, New York, 1936.
[b] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate, Confectionery and Cocoa*. Churchill, London, 1931.
[c] R. Lecoq, *Cacao*. Vigot, Paris, 1926.

d-linalool. On distillation, the early fractions were rich in esters. Hexoic, octoic and *n*-nonoic acids were stated to be present.

Brief reference is made by Tresper Clarke[18] to destruction of the adhesive properties of the mucilaginous matter holding the shell to the nib, dextrinisation of starch and hydrolysis of glycosides.

Some examples illustrating the way nib composition is affected by roasting are presented in Table XV.[19 21] Little can be gleaned from these figures beyond the fact that loss of volatile matter occurs.

7. Vacuum Drying as an Alternative to Roasting

The use of vacuum drying in place of roasting is often criticised on the ground that the final product lacks the full chocolate flavour. Nevertheless the practice is increasing and chocolate processed in this manner finds a ready market. Vacuum treatment facilitates the removal of shell. Vacuum-dried nib intended for cocoa manufacture may be subjected to a final roast after winnowing but no subsequent roasting need be given for chocolate.

8. Winnowing and Germ Separation

A. MACHINERY

Jensen[22] determined the percentage of shell in roasted cacao from different sources and found 11.6% in Arriba, 13.4% in Puerto Cabello, 9.1% in Ceylon, 13.4% in Caracas, 11.3% in Trinidad, 13.0% in Grenada and 12.1% in Accra beans.

According to Knapp[23] the proportions of the component parts of hand separated cacao beans are nibs (cotyledons) 86.7%, shell (spermoderm with adhering parts of pericarp and perisperm) 12.5% and germ (radicle) 0.8%. Mechanical separation of these components

[18] W. Tresper Clarke, *Chocolate and Cocoa*, in *Encyclopedia of Chemical Technology, Vol. III.* Interscience Encyclopedia, Inc., New York, 1949.
[19] A. L. and K. B. Winton, *Structure and Composition of Foods*, Vol. IV, John Wiley & Sons, Inc., New York, 1936.
[20] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate, Confectionery and Cocoa.* Churchill, London, 1931.
[21] R. Lecoq, *Cacao.* Vigot, Paris, 1926.
[22] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate, Confectionery and Cocoa.* Churchill, London, 1931.
[23] A. W. Knapp, *Cocoa and Chocolate.* Pitman, London, 1923.

is effected by passage through a winnowing machine and germ separator.

The shell is first cracked in a breaker by means of toothed rolls adjusted to fracture the shell without cracking the bean. When released from the shell, the nibs and germ fall apart.

Germ as well as shell is discarded in high-grade products. Separate machines may be used for segregating shell and germ. Single machines combining the two operations are also available.

In the winnowing machine, Fig. 23, beans passing from the breaker enter a rotating cylinder equipped with a series of sieves for

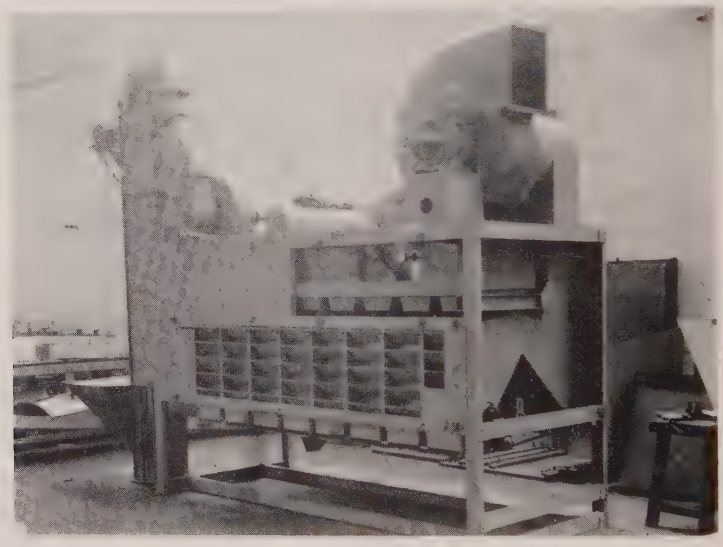


Fig. 23. Winnowing machine. (By permission of Savy Jeanjean, Paris, and Baker Perkins Ltd., Peterborough, England.)

grading the pieces in different sizes. The fractions are subjected to air currents which remove the shell by suction. Only a gentle draught is needed for the smaller pieces, otherwise some of the nib fragments will be drawn off with the shell. Suction is increased for the larger grades. Nibs and shell are delivered on opposite sides of the machine from a number of outlets.

In a typical germ separator the fragments fall onto a vibrating sieve which retains the larger pieces of nib. The germ and "smalls"

pass into a revolving cylinder with surface indentations of an appropriate size for trapping the germ.

B. EFFICIENCY OF SEPARATION

The efficiency of the winnowing machine is in the region of 99% in respect of the larger fragments. Separation of the lesser fragments is not so complete and the delivery of a small percentage of nib-shell mixtures is unavoidable. Losses can be reduced by using a secondary winnowing machine whereby from 3 to 5% of nib can be recovered from the nib-shell fractions.

Fincke[24] states that the yield of clean roasted nibs from raw beans is between 80 and 84%. According to Bywaters,[25] 100 parts of commercial Accra cacao will yield 95 parts of roasted beans, which are separated by winnowing into 81.7 parts of clean nibs, 6.7 parts of clean shell, 1.9 parts of nib containing a trace of shell, 3.8 parts of shell with a trace of nib and 0.9 part of shell-nib mixture.

Particulars relating to the performance of a Bauermeister winnowing machine are shown in Table XVI.[26]

The nib fractions which have been practically freed from shell are used for the manufacture of chocolate liquor.

TABLE XVI. Fractions of Nibs and Shell Delivered by a Bauermeister Winnowing Machine[a]

Outlet	Nib side, %		Fat, %	Shell side, %		Fat, %
1	0.04	waste	—	0.07	waste	25
2	1.01	small nib with germ	47	0.26		
3	6.27			0.84	fine	21
4	18.44	medium-sized nibs	53	0.91	medium	12
5	27.04			1.16		
6	30.64	large nibs	55	2.42	large shell	3.5
7	3.67			2.62		
8	—			4.55		

[a] H. C. J. Wijnoogst, *Chocolates after World War II.* 2nd ed., Resultat Mij, Amsterdam, 1950.

[24] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[25] H. W. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture.* Churchill, London, 1930.
[26] H. C. J. Wijnoogst, *Chocolates after World War II.* Resultat Mij, Amsterdam, 1950.

C. GENERAL COMPOSITION OF CACAO NIBS, SHELL AND GERM

The proportions of moisture, ash, fat and fat-free dry solids in cacao nibs vary slightly according to the source of the beans. The average ranges for 12 varieties of commercial cacao are shown in Table XVII.[27] The average analytical values for the main con-

TABLE XVII. COMPOSITION OF ROASTED CACAO NIBS FROM DIFFERENT SOURCES[a]

	Moisture, %	Ash, %	Fat, %	Fat-free dry solids, %
Ivory Coast	3.86	2.35	54.76	41.4
Cameroons	3.46	3.11	54.18	42.4
Ceylon	3.01	3.63	53.98	43.0
Grenada	3.49	2.36	54.82	41.7
Venezuela	3.18	3.18	54.32	42.5
Para	2.97	3.33	54.99	42.0
Arriba	2.94	3.65	53.90	43.2
Summer Arriba	3.71	3.22	54.87	41.4
Bahia	2.61	2.27	55.18	42.2
San Thomé	3.15	2.59	53.96	43.0
Trinidad	3.50	2.73	55.03	41.5
Accra	2.66	2.58	54.76	42.6

[a] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.

stituents of cacao nibs, shell and germ are presented in Table XVIII.[28,29]

9. Blending

The subtleties of flavour of cacao nibs are enhanced by judicious blending. It has been found by experience that a finer bouquet will result from a mixture of choice and ordinary varieties, in which the latter predominate, than by processing the more delicately flavoured cacao by itself. Broadly speaking, the filler grades are Forasteros and the flavouring grades are Criollo types. The heavily flavoured Arriba cacao, which falls in the Forastero group is a notable exception.

[27] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[28] *Ibid.*
[29] A. W. Knapp and A. Churchman, *J. Soc. Chem. Ind., 56,* 29 (1937).

Proportions of filler and flavour cacao are appropriately adjusted for cocoa, chocolate and milk chocolate. As the flavour grades are more expensive, the amount included will depend on the class of goods under manufacture. The present tendency is to blend only two or three varieties. In the past it was not unusual to introduce half a dozen components.

The trend in producing countries has been to replace the fine but less hardy types by more resistant trees which yield inferior grades of cacao. Efforts are now being made to re-introduce quality

TABLE XVIII. Constituents of Roasted Cacao Nibs, Shell and Germ

	Nibs	Shell		Germ
	Fincke,[a] %	Fincke,[a] %	Knapp and Churchman,[b] %	Fincke,[a] %
Moisture	5.0	11.0	3.8	7.0
Fat	53.3	3.0	3.4	3.5
Ash	2.60–3.0	6.5	8.1	6.5
Protein	10.5	13.5	14.12	24.4
Sugars	1.0	—	0.1	—
Starch	6.0	—	(2.8)[c]	—
Crude fibre	2.6	16.5	18.6	2.9
Pentosans	1.5	6.0	7.1	2.3–3.2
Tannins	5.8	9.0	5.1	—
Organic acids	2.5	—	1.12	—
Theobromine	1.45	0.75	1.3	3.0
Nitrogen-free extract	7.5	—	—	—

[a] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[b] A. W. Knapp and A. Churchman, *J. Soc. Chem. Ind., 56,* 29 (1937).
[c] No true starch is present in cacao shell.

grades. Shephard[30] points out that the future of fine types of cacao is bound up with the demand for high-class cocoa and chocolate.

Blending for cocoa or for chocolate prepared by mixing finely ground sugar and nibs is effected by the simultaneous introduction of weighed quantities of the different types of nibs into the hopper of the mill. When chocolate is made by incorporating nibs and coarse sugar, blending is done at the mixing stage.

Some recipes for chocolate blends are given in Chapter IX, 12.

[30] C. Y. Shephard, *The Cacao Industry of Trinidad, part II.* Trinidad Government Printing Office, 1932.

10. Milling

When crisp nib is ground, its tissues are torn apart and the fat within the cells is released. Friction and application of external heat cause the fat to melt and flow freely, carrying with it a suspension of particles of tissue. As the release of fat proceeds, the viscosity of the mixture decreases and the mass is discharged from the mill as a thin liquor.

The richer the nib is in fat, the more readily it will pass through the mill. Moisture content is an important factor. Bywaters[31] points out that great difficulty is encountered when dealing with low-roasted beans owing to their tendency to form a pasty mass which will not readily flow.

Cacao beans are reduced to liquor by grinding between stones, steel rolls or discs or by a combination of these methods.

A. STONE MILLS

In the usual assembly, known as the triple mill, the nibs are ground between three pairs of grooved stones, the upper one rotating and the lower one fixed. The nib falls from the hopper through the centre of the upper stone of the first pair and passes towards the outer edges during grinding. Heat developed by friction causes the fat to melt, but some additional heat is generally supplied to enable the liquor to flow more freely. Heat should be used with discretion, otherwise the flavour may be spoilt. After passage through the first pair of stones, the now fluid mass is directed through the centre of the upper stone of the second pair, to be ground to a thinner consistency and from thence, in the same manner, to the third pair of stones for still finer grinding. As the particles become finer, the rate of flow is slowed down. To regulate the output, either the speeds or the dimensions of the successive pairs of stones are increased. On leaving the last pair of stones, the liquor is run into moulds. The solidified brown blocks are known as cacao mass or chocolate liquor.

Stone mills possess certain advantages over roll mills, in that the liquor delivered has a lower viscosity and consistent size of particle, but they suffer from the disadvantage that continuous wear necessitates frequent re-cutting of the stones. This objection can be

[31] H. W. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture*. Churchill, London, 1930.

overcome by using ceramically bonded aluminum oxide (Aloxite) stones, which are more durable than the customary burr stones.[31a] Roll mills give a higher output and the resulting liquor is particularly

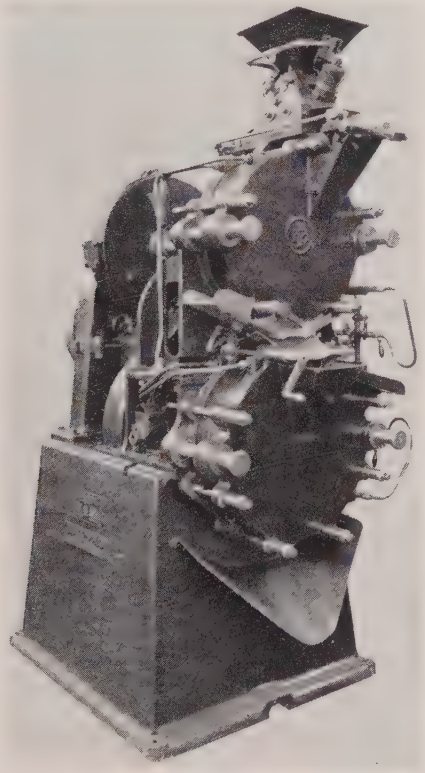


Fig. 24. Cocoa liquor disc mill. (By permission of Baker Perkins Ltd., Peterborough, England.)

suitable for chocolate manufacture because it is more easily incorporated with sugar.

B. ROLL MILLS

Roll grinding is effected by a series of hollow water-cooled steel rolls or by a combination of steel and stone rolls operating at

[31a] J. J. Alikonis, *Food Technol., 5*, 142 (1951).

different speeds. The nibs are first crushed between fluted rolls or in a disc mill. Alternatively, they may pass through a series of roughing rolls before reaching the finishing rolls for finer grinding. The rolls in modern machines are compensated for temperature changes. In this way, sagging is prevented and more even grinding and uniform wear are ensured. In some machines the cacao travels upwards. This prevents any chunks of roughly ground mass being dropped into the finer liquor.

Shortage of fats in Germany led to the design of mills for reducing the particle size to below 10 microns as a prelude to high pressing. This efficiency is claimed for the Bauermeister disc mill and three-roller combination with an output of 120 to 150 kilograms per hour. The rolls of this mill are kept lukewarm.[32]

The Buhler eight-roll mill is in two sections of four rolls for coarse grinding, placed above four finishing rolls. The Lehmann eight-roll mill is arranged in five-roll and three-roll sections and the Stollwerck mill has two fluted crushing rolls, three roughing rolls with occasional flutes and three smooth finishing rolls. It can be set for 30 to 50 microns for cocoa pressing and 70 to 80 microns for chocolate work.

C. DISC MILLS

The reduction of nibs to liquor can be performed by grinding in a disc mill. The Baker-Perkins model (Fig. 24) has two sets of gravity-fed water-cooled discs. Coarse grinding is done between the upper discs and the liquor passes to the lower set for fine-grinding.

D. CHANGES DURING MILLING

Unless the liquor has been overheated, no changes of a chemical nature occur as a result of grinding. Apart from evaporation of moisture, the only alterations are physical. The degree of refinement can be followed by viscosity measurements and microscopical examination will reveal to what extent the particle size is uniform.

[32] *British Intelligence Objectives Sub-committee Report No. 1115.* (German Chocolate Machinery.) His Majesty's Stationery Office, London, 1946.
[33] W. Tresper Clarke, *Chocolate and Cocoa*, in *Encyclopedia of Chemical Technology, Vol. III.* Interscience Encyclopedia Inc., New York, 1949.

11. Output of Chocolate Liquor and By-products from Raw Beans

By taking into account losses due to cleaning and roasting, Tresper Clarke[33] estimates that 1000 lb. of commercial cacao beans yield 948.2 lb. of roast beans, from which 808.32 lb. of clean nibs, 84.08 lb. of shell, 37.5 lb. of fine nib and shell mixture and 18.3 lb. of small nib and shell mixture can be separated after passage through the winnowing machine. By grinding the nibs, a like weight of chocolate liquor is produced (here presumably evaporation losses are ignored) for chocolate-making, fat-pressing and the manufacture of cocoa press cake. The two shell-nib mixture fractions can be processed for fat pressing (about 16.2 lb.) and theobromine extraction and the shell put to use as fertiliser or as a source of theobromine. Thus the chocolate liquor and fat expressed from the nib-shell mixtures represent a recovery of 82.45% of the raw bean.

12. Chocolate Liquor or Cacao Mass

A. DEFINITION AND REGULATIONS OF SALE IN U. S. A.

The solid or semi-plastic substance produced by grinding cacao nibs is described by a variety of names. In most European countries it is called cacao mass and in Great Britain it is also known as cocoa mass or chocolate neatwork. In the United States it is marketed as chocolate liquor, baking chocolate, chocolate coating, bitter chocolate coating or simply as chocolate. Its principal use is as the basic ingredient in the manufacture of cocoa and chocolate.

Under regulations governing the sale of chocolate liquor in the United States,[34] the cacao fat content must lie within the limits of 50 and 58% and it may be adjusted by the addition of cocoa powder or cacao fat or both to the ground nibs. Subject to satisfactory label statements, certain optional ingredients may be included. These are alkali in amount not exceeding three parts by weight of potassium carbonate or its equivalent of other alkali per hundred parts by weight of cacao nibs used, and one or more of the following flavouring or seasoning materials:

Ground spice, ground vanilla beans, any natural food-flavouring oil, oleoresin or extract.

[34] *Federal Register, 9,* No. 243, 14334 (1944).

Vanillin, ethyl vanillin, coumarin or other artificial food-flavouring.

Butter, milk fat, dried malted cereal extract, ground coffee, ground nut meats, salt.

The addition of any material which imparts a flavour imitating the flavour of chocolate, milk or butter is not regarded as legitimate.

As it has been recognised that even with the most up-to-date equipment, separated roasted nibs may contain from 1 to 1.5% of shell, a tolerance of 1.75%, calculated on alkali free nibs, is allowed by the United States Food and Drugs Administration.

The above regulations were drawn up on a fact-finding basis.

In finding 36 it is stated that the components of chocolate liquor which give its outstanding characteristics of taste, flavour, aroma and colour are in the non-fat portion. In order to express the strength of chocolate characteristics in sweet chocolate, the expression should be in terms of its non-fat portion, exclusive of any alkali or seasoning agent. A mean value of 46% of the chocolate liquor present has been accepted as a reasonable basis for such calculation. The weight of the non-fat portion when multiplied by 2.2 is a reasonable approximation of the weight of chocolate liquor present.[35]

B. ANALYTICAL CONSIDERATIONS

The average composition of German-made cacao mass (chocolate liquor) is presented in the first column of Table XIX.[36] The composition of the fat-free dry matter is given in the second column.

When cacao products are contaminated with shell, the crude fibre content is raised. When present, shell can be evaluated by determining the excess of fibre over the average content in fat-free dry cacao nibs. This method is of almost universal application and is officially recognised by the Association of Official Agricultural Chemists.[37] Lockwood[38] has shown that the respective percentages of fibre in nibs and shell vary appreciably in cacao from different sources and that different roasting treatments have some influence on the results obtained.

Rheinlander and Field[39] have drawn attention to the fact that

[35] *Federal Register*, *9*, No. 243, 14331 (1944).
[36] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[37] *Official Methods of Analysis of the A.O.A.C.* 7th ed., A.O.A.C., Washington, D. C., 1950.
[38] H. C. Lockwood, *Analyst*, *64*, 92 (1939).
[39] A. H. Rheinlander and V. H. Field, *Analyst*, *68*, 112 (1943).

winnowing and sieving tend to produce fractions of shell with widely differing fibre content because it is not homogeneous but consists of a number of botanically differentiated layers in which lighter fractions contain only 9.5% of fibre on a fat-free dry basis, compared with 20.5% in heavier layers. They therefore favour microscopical counts for detection and determination of shell.

TABLE XIX. AVERAGE COMPOSITION OF CACAO MASS MANUFACTURED IN GERMANY[a]

	Cacao mass (chocolate liquor), %	Fat-free dry cacao mass, %
Moisture	2.0	—
Fat	55.0	—
Ash	2.68–3.09	6.23–7.19
Protein	10.8	25.1
Sugars	1.0	2.4
Starch	6.2	14.4
Crude fibre	2.7	6.2
Pentosans	1.7	3.5
Tannins[b]	6.0	14.0
Organic acids	2.5	6.0
Nitrogen-free extract	7.7	18.0
Theobromine	1.5	3.49

[a] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[b] In a private communication to the author, Fincke states that more recent results were appreciably higher.

Winkler[40] determined the percentages of certain constituents which are common to defatted nibs and shell and calculated their ratios on a fat-free basis. Results reported by him are presented in Table XX. Although the most striking differences were observed for mineral constituents, especially silica, water-soluble alkalinity and iron, he pointed out that difficulties of interpretation were likely to arise when the raw beans were clayed (see p. 107) and recommended the crude cellulose content as providing a more reliable indication of the presence of shell.

As a result of collaborative work, a method of assessing cacao shell-content by means of pectic acid determination has now become official in the United States.[41]

[40] W. O. Winkler, *J.A.O.A.C., 18,* 427 (1935).
[41] Report on Cacao Products, *J.A.O.A.C., 35,* 71 (1952).

The simplest means of assaying the non-fat cacao in mixtures of chocolate liquor with sugars is by determining the quantity of cold water-insoluble matter in the dry, defatted sample. Total cacao solids are then calculated on the basis that dry, fat-free unalkalised nibs contain 76% of insoluble matter.

TABLE XX. Distribution of Certain Constituents in Cacao Nibs and Shell[a]

	Fat-free nib	Fat-free shell	Ratio % in shell / % in nibs
Ash	5.30%	8.81%	1.7
Water-insoluble ash	3.00%	3.71%	1.2
Water-soluble ash	2.30%	5.10%	2.2
Water-soluble alkalinity (c.c. 0.1 *N* per gram)	1.66	5.48	3.2
Water-insoluble alkalinity (c.c. 0.1 *N* per gram)	5.13	6.98	1.4
Acid-insoluble ash	0.14%	1.07%	7.5
Cl	0.058%	0.035%	0.6
P_2O_5	1.76%	1.18%	0.7
SiO_2 insoluble	0.002%	0.58%	322
SiO_2 soluble	0.011%	0.14%	12.7
SO_4	0.60%	0.64%	1.1
CaO	0.21%	0.38%	1.8
Fe	0.004%	0.013%	3.2
K_2O	1.91%	3.38%	1.8
Mn	0.003%	0.004%	1.3
MgO	0.95%	1.07%	1.1
Citric acid	0.29%	0.10%	0.3
Lignin (saturated HCl method)	24.9%	29.0%	1.2
Lignin (72% H_2SO_4 method)	22.0%	24.3%	1.1
Crude cellulose	3.16%[b]	20.66%	6.5

[a] W. O. Winkler, *J.A.O.A.C., 18,* 427 (1935).
[b] (Cacao liquor).

In more complicated mixtures, the theobromine content may be used as an index of the fat-free cacao solids present.[42] Moir and Hinks[43] elaborated a method for determining the sum of theobromine and caffeine in cacao products and calculated a mean conversion factor based on nib analysis.

[42] R. V. Wadsworth, *Analyst, 46,* 35 (1921).
[43] D. D. Moir and E. Hinks, *Analyst, 60,* 439 (1935).

"Anthocyan-red," derived from catechol tannins has been proposed by Thaler and Wieseler[44] as a means of evaluating cacao in manufactured products.

In all the above methods of analysis, average values for cacao constituents must be relied on if the source is unknown. Some analytical results quite outside the usual range for ground cacao nibs have been recorded for seven samples from Spanish possessions in Africa as follows:

Moisture 3.98–4.30%, nitrogenous matter 16.51–19.31%, ash 2.50–4.46%, starch 13.68–16.61%, cellulose 2.09–2.69%, theobromine 1.11–1.29%, fat 42.56–46.15%. It was stated that the fat content was low, because it was not completely extracted even after eight days.[45]

13. By-Products

A. CACAO SHELL

(1) COMPOSITION

Cacao shell is the most considerable by-product of the cocoa and chocolate industry. With the world output of raw cacao beans in the neighbourhood of 700,000 tons, at least 50,000 tons of roasted shell are available for disposal annually.

An indication of the differences in the general composition of nibs and shell can be obtained by consulting Tables XVIII and XX.

The fat (shell butter) content of commercial shell is variable and fluctuates according to the amount of fat transferred from the nibs through roasting and the efficiency of the winnowing machine in separating nibs from shell.

Cacao shell butter is a deep yellow coloured solid and melts to a dark brown liquid. On account of its high acid value, shell butter is not acceptable as human food. It contains a considerable amount of unsaponifiable matter and is also distinguished from cacao butter by its lower saponification number and higher iodine value and refractive index. The chemical and physical characteristics are set out in

[44] C. L. Hinton, *British Intelligence Objective Sub-committee Evaluation Report 560.* (Containing abstract of unpublished communication by H. Thaler and H. Wieseler.) His Majesty's Stationery Office, London, 1946.
[45] G. Folch Jou, *Ion, 6,* 125 (1946); *C.A., 40,* 4448 (1946).

Table XXI.[46-48] Seber[49] determined the unsaturated acids in the glycerides of shell butter and found 31.9–40.5% of oleic acid and 7.8–14.5% of linoleic acid. From the unsaponifiable portion of the fat, he isolated sitosterol isomers, paraffin hydrocarbons and unsaturated hydrocarbons by chromatographic analysis on an alumina column.

TABLE XXI. CHEMICAL AND PHYSICAL CHARACTERISTICS OF CACAO SHELL BUTTER

	Fincke[a]	Galanos[b]	Seber[c]	
Zeiss butyrorefractometer 40°C	47.3–57.2	56.0		54.2–61.2[d]
Melting point, clear	38°C.–50°C.	—		
Acid value	3.0–64.0	—	13.7– 47.1	
Saponification value	189–202	180	168.8–180.5	
Unsaponifiable matter	—	—	7.1– 13.8	8.9–14.5[d]
Iodine value	39.9–41.4	39	50.7– 59.8	52.6–61.4[d]
Melting point of fatty acids (clear)	50.6°C.–51.5°C.	—		
Iodine value of fatty acids	41.8–43.1			50.1–58.5[d]

[a] H. Fincke, *Die Kakaobutter und ihre Verfälschungen.* Wissenschaftliche Verlagsgesellschaft, Stuttgart, 1929.
[b] S. Galanos, Z. *Unters. Nahr. und Genussm., 48,* 212 (1924).
[c] L. Seber, *Gordian, 45,* No. 1057, 14 (1939).
[d] From unroasted shell.

TABLE XXII. MINERAL CONTENT OF ROASTED CACAO SHELL[a]

	African, %	Guayaquil, %	Ceylon, %
Total ash	5.63	8.19	6.61
Water-soluble ash	3.53	5.25	4.78
Alkalinity as K_2O	2.63	3.36	2.54
Sand	1.79	1.45	1.00

[a] N. P. Booth, *Analyst, 34,* 143 (1909).

Labbé, de Balsac and Lerat[50] extracted α- and β-theosterols from the unsaponifiable portion of shell butter. They state that β-theosterol can fix ultraviolet rays and thus resembles ergosterol in acquiring anti-rachitic properties.

[46] H. Fincke, *Die Kakaobutter und ihre Verfalschungen.* Wissenschaftliche Verlagsgesellshaft, Stuttgart, 1929.
[47] S. Galanos, *Z. Unters. Nahr. und Genussm., 48,* 212 (1924).
[48] L. Seber, *Gordian, 45,* No. 1057, 14 (1939).
[49] L. Seber, *Gordian, 45,* No. 1057, 14 and No. 1060, 12 (1939).
[50] H. Labbé, F. H. de Balsac and R. Lerat, *Bull. soc. therap. 35,* No. 11, 71 (1930); *C.A., 25,* 729 (1931).

Clarenz and Pfeiffer[51] found that 57.8% of the total protein is digestible. Digestibility is reduced by high roasting.

Although shell contains only about 1% of theobromine, this is sufficient for profitable extraction on the commercial scale.

Owing to its high cellulose content, cacao shell is unsuitable for human food. Thaler[52] determined the skeletal substances in dry shell on an ash-free basis and found from 29.07% (Bahia) to 34.51% (Accra). The latter was composed of cellulose 28.15, xylan 4.94 and acetyl 1.43%. A fairly constant ratio appears to exist between cellulose content and furfurol value (furfurol is derived from pentosans) for all varieties of beans.

The crude fibre content of dry, fat-free shell is approximately three times that of fat-free dry nib. The importance of this difference as a basis for estimation of shell in cacao products is discussed in section 12B of this chapter.

Lecoq[53] mentions that 5.90% of pectin is present in cacao shell. Winkler[54] found an average value of 4.5% of pectic acid on a dry, fat-free basis.

No starch is present in hand-separated shell. Any which is found in commercial shell is derived from adhering particles of cotyledons.

According to Jensen[55] the mineral content of cacao shell is between 5.3 to 8.9% and the water-soluble ash, of which potash is the main constituent, ranges from 3.5 to 5.7%. The total ash, water-soluble ash, alkalinity as K_2O and sand content of roasted cacao shell from three different sources are shown in Table XXII.[56]

The average water-soluble alkalinity, calculated as potash, is in the neighbourhood of 40% of the total ash. The mean percentages of other constituents in the ash of 28 varieties of cacao are given by Luhrig[57] as CaO 5.8, MgO 10.4, Fe_2O_3 2.7, Al_2O_3 2.0, Mn_2O_3 0.02, P_2O_5 8.9, SO_3 3.5, Cl 2.4, soluble SiO_2 5.6, sand 11.3%.

[51] G. Pfeiffer and L. Clarenz, *Biochem Z., 285,* 195 (1936).
[52] H. Thaler, *Z. Untersuch. Lebensm., 78,* 129 (1937).
[53] R. Lecoq, *Cacao.* Vigot, Paris, 1925.
[54] W. O. Winkler, *J.A.O.A.C., 23,* 593 (1940).
[55] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate Confectionery and Cocoa.* Churchill, London, 1931.
[56] N. P. Booth, *Analyst, 34,* 143 (1909).
[57] H. Luhrig. *Z. Untersuch. Nahr. und Genussm., 9,* 263 (1905).

(2) USES OF CACAO SHELL

The value of cacao shell as a feeding stuff is limited by the presence of theobromine. Bartlett[58] states that adverse symptoms are likely to occur when the daily intake of theobromine exceeds 0.025 gram per kilogram of body weight. Fatalities have occurred among horses when the daily intake was 0.027 gram per kilogram body weight and upwards.

Knapp and Coward[59] estimated that 1 gram of sun-dried Accra cacao shell contains 28 international units (0.7γ) of vitamin D (calciferol) by comparing its curative effect on rats in which rickets had previously been induced, with controls receiving doses of ergosterol.

Kon and Henry[60] demonstrated that the vitamin D content of milk is improved when cacao shell is included in the diet of milking cows. This observation was confirmed by Golding and Burr.[61]

The demand for cacao shell as fodder is insufficient to absorb the entire output. It is used also as a fertiliser and even as fuel. Schuler[62] estimates its fuel value as 4000 calories per kilogram. He recommends that it should be burnt separately and the resulting ash sold as fertiliser containing 15–18% of alkali and 10–12% of phosphate.

A patent has been granted for the use of cacao shell as a filler for thermosetting resins in the plastics industry.[63]

The soluble tannins and related substances can be extracted from cacao shell for use in compositions for preventing the formation of boiler scale and also as flocculating agents.

One pound of husks to 1.25 gal. of water is heated in an autoclave with direct steam injection. The extract, which contains protein, carbohydrates and tannins, is drained off immediately after the mixture attains steam temperature. The extract may be used to bring about flocculation of colloidal and semi-colloidal solutions and to prevent crystallisation from saturated and super-saturated solutions.[64]

[58] S. Bartlett in *Report and Proceedings of the Cocoa Research Conference 1945*. His Majesty's Stationery Office, London, 1945.
[59] A. W. Knapp and K. H. Coward, *Biochem. J., 29*, 2728 (1935).
[60] S. K. Kon and K. M. Henry, *Biochem. J., 29*, 2051 (1935).
[61] A. Golding and J. Burr, *Agr. Progress, 14*, No. 1, 44 (1937).
[62] M. Schuler, *Bull. Officiel de l'Office Internat. du Cacao et du Chocolat*, Special issue, Sept. 1937, p. 43.
[63] U. S. Pat. 2,376,607 (22nd May 1945), J. H. Lune and R. L. Schafer for Monsanto Chemical Co.
[64] Brit. Pat. 587,053 (11th Apr. 1947), J. R. Havelock, H. B. A. Parr-Burman, F. Elkington, W. G. Gilpin and the British Periclase Co., Ltd.

The extraction of theobromine from cacao shell is an industry of increasing importance. Commercial extraction procedures are briefly outlined in Section D below.

B. GERM

(1) COMPOSITION

In Table XVIII[28,29] the percentages of the main constituents of cacao germ are presented for comparison side by side with those of nibs and shell.

Like cacao shell butter, cacao germ oil has a high acid value and contains a considerable amount of unsaponifiable matter. Its melting point, 30.5°C., is lower than that of cacao butter and the range for Zeiss butyrorefractometer readings at 40°C. (54.0–62.6) is considerably higher.[65] Seber[66] recorded acid values from 20.3 to 26.2, saponification value 164.9–176.4, unsaponifiable matter 7.9–15.6, and iodine values from 67.5 to 85.1 for germ oil. He found that the proportions of oleic and linoleic acid varied considerably according to the source of cacao,[67] the extreme values being 44.8% of oleic acid and 14.8% of linoleic acid in Arriba germ oil and 9.8% of oleic acid and 42.3% of linoleic acid in San Thomé germ oil. By chromatographic analysis Seber[68] separated the unsaponifiable matter into stigmasterol, sitosterol isomers, paraffin hydrocarbons, unsaturated liquid hydrocarbons and α-theosterol fractions.

By comparing the curative effect of germ oil on rats from whose diet vitamin A had been excluded with controls receiving β-carotene, Seber[69] estimated that 100 grams of the oil contain 825 to 1400 international units (189–311 μg.) of provitamin A.

Vitamin D is present in the oil from sun-dried cacao germ. Knapp and Coward[70] attributed the exceptionally high vitamin D content of a sample of milk chocolate to the fact that it was prepared with cacao which had not been germ-separated.

According to Haussler[71] cacao germ contains 0.44% of dextrose and 2.15% of sucrose. He mentions a crude fibre content of 5.26%.

[65] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[66] L. Seber, *Gordian, 45,* No. 1059, 12 (1939).
[67] L. Seber, *Gordian, 45,* No. 1057, 14 (1939).
[68] L. Seber, *Gordian, 45,* No. 1060, 12 (1939).
[69] L. Seber, *Gordian, 45,* No. 1059, 12 (1939).
[70] A. W. Knapp and K. H. Coward, *Analyst, 59,* 474 (1934).
[71] H. P. Haussler, *Arch. Pharm., 252,* 82 (1914).

Cacao germ is rich in protein. Fincke (see Table XVIII) gives a mean value of 24.4% for protein and 3% for theobromine. Haussler[72] records 1.88% of theobromine and 0.21% of caffeine.

Potash is the main mineral constituent of germ. Hartel[73] found K_2O 37.1, CaO 5.2, MgO 13.1, P_2O_5 24.1 and SO_3 5.2 parts per 100 parts of ash.

(2) USES

An argument in favour of the inclusion of cacao germ in cheaper lines of cacao products is that some benefit is derived from the vitamins present. Because of its grittiness, germ is usually removed during the manufacture of high-grade goods. Commercially separated germ is not entirely freed from nibs. The fat content is thereby enhanced and may amount to 15%. Fat recovered by solvent extraction is dark coloured and has an unpleasant taste and smell unless subjected to refining treatment.

Cacao germ contains sufficient theobromine to repay its extraction.

C. SHELL-NIB MIXTURES

(1) COMPOSITION

The composition of shell-nib mixtures depends on the efficiency of the winnowing machine. According to Wadsworth and McLellan[74] the range of composition is: Moisture 5%, fat 10–38%, protein 18–22%, crude fibre 8–12%, carbohydrate 30–50% and theobromine 1.5–2.5%.

(2) USES

When the fat content of nib-shell mixtures is sufficiently high, it is worth while to remove it by pressing. Very little shell butter will be present in the expressed fat which has physical and chemical characteristics almost identical with those of cocoa butter obtained by pressing chocolate liquor. The press cake remaining after pressing is known as expeller cake and will contain 10–15% of residual fat

[72] H. P. Haussler, *Arch. Pharm., 252*, 82 (1914).
[73] F. Hartel, *Z. Untersuch. Lebensm., 47*, 265 (1924).
[74] Private comm. by R. V. Wadsworth and B. G. McLellan cited by S. Bartlett in *Report and Proceedings of the Cocoa Research Conference 1945*, His Majesty's Stationery Office, London, 1945.

which can be removed by solvent extraction and is marketed as extracted cocoa butter. It contains a fairly high proportion of shell butter. The addition of solvent-extracted fat to expressed cocoa butter is usually regarded as an adulteration.

The residue remaining after solvent extraction contains only about 1% of fat and is known as cocoa cake meal. It contains 2–3% of theobromine most of which can be extracted for use in medicinal preparations.

D. THEOBROMINE EXTRACTION

Theobromine forms soluble salts with sodium or calcium hydroxides and magnesium oxide. These alkaline substances can be used to extract theobromine from by-products of the cocoa and chocolate industry. The choice of calcium hydroxide is convenient, because theobromine is readily liberated from its calcium salt by means of carbon dioxide. Calcium carbonate is precipitated and theobromine can be purified by crystallisation. Extraction by this means is never quite complete and the "detheobrominised" cacao meal residue will contain about 0.5% of theobromine and 20% of lime which restrict its use as a feeding stuff.[75]

Only a comparatively small proportion of theobromine extracted from cacao by-products is used directly in medicinal preparations. The bulk of it is converted into caffeine by methylation.

Tresper Clarke[76] cites nine patents for theobromine extraction by alkali treatment, three patents involving solvent-extraction, one patent relating to the sublimation of theobromine during distillation and one patent for the selective adsorption of theobromine and caffeine on clay.

[75] S. Bartlett in *Report and Proceedings of the Cocoa Research Conference 1945.* C.P. 27. His Majesty's Stationery Office, London, 1945.

[76] W. Tresper Clarke, *Chocolate and Cocoa,* in *Encyclopedia of Chemical Technology, Vol. III.* Interscience Encyclopedia Inc., New York, 1949.

CHAPTER VIII

MANUFACTURE OF COCOA BUTTER AND COCOA POWDER

1. Alkalisation

Table XXIII, due to Mosimann,[1] shows the distribution of organic acids in cacao nibs, the variations in the ratio of free acid to total acid, and pH values for different types of cacao. Judicious blending gives rise to greater uniformity of acid content in chocolate liquor. When used for the manufacture of cocoa powder, the liquor is generally treated with alkali to improve the colour and develop the flavour. The practice originated in Holland and is known as the "Dutch" process. As an innovation it met with fierce opposition from some quarters, but the attitude has now changed, and it is estimated that 90% of the cocoa marketed at the present time is alkalised.[2] Alkalised cocoa is known commercially as "soluble cocoa," because the particles remain in suspension for a longer time after preparation of the beverage than is the case when unalkalised cocoa is infused. No marked increase in solubility actually occurs. It is claimed that the treatment is justified by the increased digestibility of the proteins and a reduction in astringency arising from a partial condensation of the tannins.[3] The latter reaction is responsible for the enrichment of the colour. The extent to which these changes take place will depend on the degree of alkalisation.

The amount of alkali used for the preparation of soluble cocoa is adjusted to bring about partial rather than complete neutralisation. Saturated solutions of sodium or potassium carbonate or bicarbonate

[1] Table XXIII. Organic Acids in Cacao Nibs. G. Mosimann, *Internat. Choc. Review, 2,* 186 (1947).
[2] H. W. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture.* Churchill, London, 1930.
[3] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate, Confectionery and Cocoa.* Churchill, London, 1931.

TABLE XXIII. Percentage of Organic Acids in Air-Dried Cacao Nibs and Fat-Free Dry Cacao Mass (Chocolate Liquor)[a]

	Bahia		Trinidad		Arriba I		Arriba II		P. Cabello		Java		Accra		St. Thomé	
	Nibs, %	F.F.D. Mass, %	Nibs, %	F.F.D. Mass, %	Nibs, %	F.F.D. Mass, %	Nibs, %	F.F.D. Mass, %	Nibs, %	F.F.D. Mass, %	Nibs, %	F.F.D. Mass, %	Nibs, %	F.F.D. Mass, %	Nibs, %	F.F.D. Mass %
Acetic	0.44	1.05	0.35	0.78	0.40	0.95	0.41	0.95	0.19	0.43	0.39	0.92	0.24	0.50	0.71	1.67
Citric	0.45	1.07	0.55	1.23	0.57	1.36	0.50	1.15	0.63	1.50	0.75	1.77	0.54	1.32	0.43	1.08
Oxalic	0.34	0.81	0.32	0.72	0.45	1.07	0.41	0.95	0.44	1.00	0.50	1.18	0.35	0.88	0.35	0.82
Total	1.23	2.93	1.22	2.73	1.42	3.38	1.32	3.05	1.29	2.93	1.64	3.87	1.14	2.79	1.52	3.57
Free acid	—	2.67	—	2.34	—	2.18	—	2.18	—	1.89	—	1.98	—	2.46	—	3.13
Free acid × 100 / Total acid		91.2		85.8		64.5		71.5		64.5		51.1		88.1		87.7
pH	4.4	—	4.5	—	5.0	—	5.3	—	5.3	—	5.2	—	5.2	—	4.5	—

[a] G. Mosimann, *Internat. Choc. Rev.*, *2*, 186 (1947).

are most generally used, while ammonia, ammonium carbonate, magnesium oxide or carbonate or mixtures of certain of the above chemicals are favoured by some manufacturers.

Alkali may be introduced prior to roasting or at the nib stage, but it is more economical to mix it with chocolate liquor. The process is conducted on the following lines.

Warmed chocolate liquor is run into a steam-jacketed mixer and the temperature is raised to 70°C. before admitting the alkaline solution. It is advisable to add the alkali in two portions, on account of its thickening effect on the liquor. Excess moisture is driven off by raising the temperature but this should not exceed 115°C.[4] Sometimes the alkali is partially neutralised by acid, but this step is unnecessary when only 1% of alkali has been added. When ammonia is used, it is introduced in the form of a 10% solution or by means of a mixture of sodium and ammonium carbonates which generates ammonia.

Some recipes for alkalisation which deviate from the more general methods are to be found in reports on German procedure.[5] In one large undertaking, sodium nitrate was used as an ingredient of an alkali mix, made up as follows:

40 kg. sodium bicarbonate
15 kg. sodium nitrate
} in 32 litres of distilled water

2.5 litres of the above were added to a mixture containing

20 kg. potassium carbonate
8 kg. ammonium carbonate
} in 150 litres of distilled water

and the whole added to 1500 kg. of roasted nib, which was then dried for 2 hours in a roaster of one and a half tons capacity. After grinding, the liquor was run into steam-jacketed containers of 750-kg. capacity and the liquor then neutralised with 1 kg. glacial acetic acid in the presence of 4 kg. of gelatin solution, the concentration of which was not stated.

[4] H. W. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture*. Churchill, London, 1930.

[5] *British Intelligence Objectives Sub-Committee Report No. 1077*. German Chocolate, Cocoa and Confectionery Layout. His Majesty's Stationery Office, London, 1946.

2. Pressing

When about three-quarters of the fat is expressed from chocolate liquor, a hard cake containing about 22–24% of fat remains. This cocoa cake or press cake is made into cocoa powder by pulverisation. The expressed fat is known as prime cocoa butter or press butter. To meet the demand for cocoa butter, chocolate liquor may be subjected to more drastic pressing, leaving a cake containing only 10% of fat

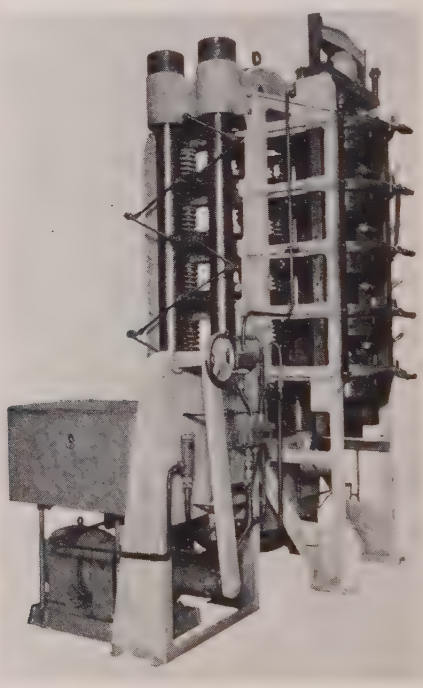


Fig. 25. Carver five-pot hydraulic cocoa butter press. (By permission of Baker Perkins Ltd., Peterborough, England.)

or even less. Other sources of cocoa butter are shell-nib mixture and even whole roasted beans (broken and double beans can be used up in this way) which are subjected to pressure in an expeller press. The expressed fat thus obtained is inferior to prime cocoa butter and requires refining before use. The residue, known as "expeller cake" is unsuitable for human diet on account of the shell present.

A. COCOA PRESS

Metal press pots capable of accommodating 40 lb. of chocolate liquor are fitted with felt pads or sieves of rustless metal at both top and bottom. In the Carver press illustrated (Fig. 25), the pots can be slid out to receive the charge of warmed liquor (76–77°C.). When they are returned to position in the frame, hydraulic pressure is applied by means of a ram. Pistons working telescopically with gradually increasing pressure force out the warm fat which is extruded through the perforations and collected in suitable receptacles. It is advisable to cool the butter rapidly to below 24°C. before running it into moulds. The filter pads retain practically all the solid material, but the molten fat is slightly brown when delivered from the press, owing to the presence of particles of cacao which have penetrated through the pads. No refinement is necessary when the cocoa butter is going to be used for chocolate making. When the cocoa butter is destined for pharmaceutical purposes, the sediment must be removed by filtration or by passage through a plate press.

Flavour of both press cake and butter is impaired by excessive heat during pressing.

B. COCOA BUTTER

(1) PROPERTIES

At ordinary temperatures, cocoa butter is a pale yellow, brittle crystalline solid which melts to a golden yellow oil. When it has been overheated during pressing, it sets to a dull greyish white mass. It usually has a faint chocolate aroma and cannot easily be deodorised. Roasting temperature has some influence on flavour, which tends to be less bland when the butter is expressed from low-roast beans. Fincke[6] asserts that roasting and alkalisation cause very little alteration which can be chemically detected. On the other hand, Vaubel[7] reported a higher saponification value (229.7) and iodine value (48.2) for the crude fat from raw cacao beans than the normal values for commercial cocoa butter (see also Chapter V, 1D).

Under satisfactory storage, cocoa butter has excellent keeping qualities due to the presence of fat-soluble antioxidants. Prolonged exposure to sunlight causes it to develop a rancid taste and smell

[6] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[7] W. Vaubel, *Z. angew. Chem., 37, 222* (1924); *J. Soc. Chem. Ind.*, 524B (1924).

and the oil becomes bleached through the oxidation of the unsaturated lipochrome pigments.[8]

According to Fincke,[9] the specific gravity of solid cocoa butter is 0.976–0.978 at 15°C., but Elsdon[10] cites 0.990–0.998 at 15°C. and 0.973 at 25°C. Its viscosity, 46–49, is higher than that of butter fat or coconut oil.[11] The usual range for incipient melting point is 31.8–33.5°C. and complete fusion occurs between 32° and 35°C. To comply with the standards for Theobroma Oil of the United States Pharmacopeia and the British Pharmacopoeia, the melting point must be within the range of 30–35°C.

Elsdon[12] states that the value of cocoa butter in pharmacy is due to the fact that although it is hard and brittle at ordinary temperatures, it melts below blood heat. The fat solidifies at 29–34°C.

According to Fincke,[13] the incipient melting point of the fatty acids is 49–51°C. and complete fusion occurs at 51.5–53.5°C. Elsdon[14] cites a range of 49–51°C. The standard laid down in the U. S. P. for the solidifying point of the fatty acids is 49–50°C.

U. S. P. limits for the refractive index at 40°C. (1.4537–1.4578) are wider than the range (1.4565–1.4575) prescribed in the B. P.

Normally the acid value of cocoa butter is below 2.8. The B. P. (1948) limit is 3.0. Previously it was 4.0.

U. S. P. and B. P. limits for the saponification value are from 188 to 195 and for iodine values from 35 to 40.

Only traces of volatile fatty acids are present in cocoa butter, judging from the low Reichert-Meissl values of typical specimens (0.3–1.0). Polenske and Kirschner values are of the same order.

Cocoa butter is only barely soluble in 90% ethyl alcohol and is readily soluble in diethyl ether, light petroleum, chloroform, carbon tetrachloride and benzene. By the behaviour of an ethereal solution, it is possible to detect the presence of added stearin or tallow. When one gram of the fat is dissolved in 3 ml. of ether in a test tube at 17°C. and placed in water at 0°C. the mixture should not show any deposit in less than three minutes. When the congealed solution is

[8] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[9] *Ibid.*
[10] G. D. Elsdon, *Edible Oils and Fats*. Benn, London, 1926.
[11] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936
[12] G. D. Elsdon, *Edible Oils and Fats*. Benn, London, 1926.
[13] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[14] G. D. Elsdon, *Edible Oils and Fats*. Benn, London, 1926.

brought to a temperature of 15.5°C., it should not exhibit more than a slight turbidity.

Theobroma oil, B. P., is defined as the solid fat which is expressed from the roasted seeds of *T. cacao,* Linn. Solvent-extracted fat may be detected by examining a solution in petroleum ether in ultraviolet light. A strongly fluorescent sample is either solvent-extracted or contains mineral oil from factory waste.[15]

(2) COMPOSITION

Glycerides. Hilditch and Lea[16] found that the glycerides of cocoa butter are distributed as follows: Fully saturated glycerides 2.5%, monooleodi-saturated glycerides 73.0% and dioleomono-saturated glycerides 24.5%.

The individual glycerides were determined to the nearest unit by Hilditch and Stainsby[17] who found oleopalmitostearin 52%, oleodistearin 19%, stearodiolein 12%, palmitodiolein 9%, oleodipalmitin 6% and saturated palmitostearins 2%. The small proportion (2%) of linoleic components has not been considered separately, but is included in the oleoglycerides.

From the melting points of fully saturated hydrogenation products, obtained by fractional crystallisation, Hilditch and Stainsby conclude that the palmitic groups in the monopalmitic glycerides are mainly in the β position and that the oleic group in the oleodipalmitin is largely present in the α form. Both α and β stearodioleins are present.

On account of the temperature range for solidification of the various components of cocoa butter, much attention has to be devoted to the correct conditions for tempering chocolate goods, so that the fat crystals are distributed in a stable form. Particular care is required for the maintenance of such a condition during storage.

Phosphatides. Conflicting results obtained by different investigators make it difficult to form an opinion as to the exact quantity of lecithin present in cocoa butter. The bulk of cacao lecithin does not appear to be distributed in the fat, but occurs in combination with the protein. For its estimation the methods of approach are from the phosphorus and choline content. By incinerating press butter with

[15] W. T. Field, *Analyst, 55,* 744 (1930).
[16] T. P. Hilditch and C. H. Lea, *J. Chem. Soc.,* 3106 (1927); *J. Soc. Chem. Ind.,* 41T (1929).
[17] T. P. Hilditch and W. J. Stainsby, *J. Soc. Chem. Ind.,* 95T (1936).

lime and determining the phosphate, Fincke[18] arrived at a maximum of 0.10% of lecithin. In ether-extracted cocoa butter, he found 0.10% for Accra and 0.29% for Java Criollo cacao. Rewald[19] found from 0.07% (Puerto Cabello) to 0.26% (Arriba) of total lecithin in cacao, but only traces in cocoa butter. By calculation of the choline content from nitrogen determinations, Nottbohm and Mayer[20] reported only a trace of lecithin in ether-extracted fat and from its relatively high phosphorus content they concluded that other phosphorus compounds in addition to lecithin are extracted. This may be the explanation of the high value of 0.59% of lecithin, calculated by Braunsdorf,[21] from the phosphate content of ether-extracted fat.

Unsaponifiable Matter. The amount of unsaponifiable matter in genuine cocoa butter is normally below 0.8%.[22] When larger quantities are found, contamination with germ oil or shell butter may be suspected.

No appreciable amount of β-carotene has been recorded in cocoa butter.

Bolton and Williams[23] classified a wide range of animal and vegetable fats and oils according to the iodine absorption by the unsaponifiable matter. A group with iodine values from 90 to 96 embraces fish and marine animal oils. Cocoa butter is the only vegetable oil in this class. Most of the seed oils belong to the next group (iodine value 117–124) which includes Borneo tallow, well known as a substitute for cocoa butter.

Ash. The amount of mineral matter in cocoa butter is exceedingly small. Fincke[24] gives a mean value of 0.006%.

(3) USES OF COCOA BUTTER

The main use of cocoa butter is in the manufacture of chocolate. When it is added to a mixture of chocolate liquor and sugar, it enables the chocolate to be moulded into firm blocks. Other important outlets

[18] H. Fincke, *Die Kakaobutter und ihre Verfälschungen.* Wissenschaftliche Verlagsgesellschaft m.b.H., Stuttgart, 1929.
[19] B. Rewald, *Bull. Officiel de l'Office Internat. du Cacao et du Chocolat*, 1, 133 (1931).
[20] F. E. Nottbohm and F. Mayer, *Z. Untersuch. Lebensm., 65*, 55 (1933).
[21] K. Braunsdorf, *Z. Untersuch. Lebensm., 73*, 38 (1937).
[22] H. Labbé, F. H. de Balsac and R. Lerat, *Bull. soc. therap., 35*, No. 11, 71 (1930); *Chem. Abstracts, 25*, 729 (1931).
[23] E. R. Bolton and K. A. Williams, *Analyst, 55*, 5 (1930).
[24] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.

for cocoa butter are found in the manufacture of pharmaceutical preparations and cosmetics.

Solvent-extracted cocoa butter, obtained from expeller cake, can be used in the manufacture of soap. Cocoa butter prepared by pressing low-grade raw beans in the country of origin also goes to soap-making.

(4) COCOA BUTTER SUBSTITUTES

Types of fat known commercially as *illipe* butter are used as substitutes for cocoa butter. They are not derived from *Bassia longifolia,* the true source of illipe fat, but consist of Borneo tallow (the fat expressed from *Shorea* and *Palaquium oblongifolium*) and Chinese vegetable tallow extracted from *Stillingia sebifera.* They differ in appearance from cocoa butter by their greenish tinge which is more noticeable when the fat is melted, and they are also distinguished by the absence of smell.

Hardened vegetable fats are also used to replace cocoa butter and oils of the coconut class are included as ingredients of couvertures for ice cream, etc.

Methods for detection of "illipe butter" and hardened fats are included in Chapter XI, D2 and D3.

3. Manufacture of Cocoa Powder from Press Cake

A. BREAKING AND GRINDING

When delivered from the press, cocoa cake is very hard and it is more conveniently broken up while it is still warm. Before reaching the pulveriser, it is reduced to lumps about the size of a cacao bean. In the pre-breaker it is torn up between toothed rollers or in spiked drums. The fragments are cooled before being pulverised. For this operation several types of mill are available. Their suitability depends to some extent on the fat content of the cake and the degree of refinement of the original liquor. Should further grinding be necessary, a covered machine resembling a chocolate melangeur (see Fig. 26) or more modern machines such as disc and hammer mills will answer the purpose.

A disintegrator or a cone mill will serve for pulverisation when no further grinding is necessary. Temperature control between 25° and 30°C. is maintained by passing a stream of cold air below the

pulveriser to prevent liquefaction of the fat, otherwise the color of the cocoa powder will deteriorate and it will appear dull and lustreless.

Flavouring ingredients may conveniently be introduced at this stage. It is practicable to dilute the flavouring material with some previously ground cocoa and then add the mixture to the bulk of broken press cake for distribution. Flavourings and spices commonly used are vanillin, cinnamon, almond flavour and tolu balsam. Malted barley and ground hops are incorporated in the British product marketed as "Vi-cocoa."

B. SIFTING

A preliminary tempering will assist and improve the colour and texture of the product. With this aim in view, the powder leaving the mill meets a blast of cold air (5° to 8°C.) and is conveyed to a tempering chamber where it is maintained in suspension at 15° to 18°C. for ten to fifteen minutes. This treatment removes superfluous moisture, discourages the formation of clots and imparts the correct consistency. The tempered powder then travels to the sifter.

(1) SCREENING

The pulverised cocoa is passed through a fine silk screen. In one type of equipment, it is thrust by centrifugal force through a revolving silk gauze cylinder. The pores are kept open by brushing or by means of a beating mechanism. Tailings (large particles or aggregates) are returned to the mill for re-grinding. An alternative form of sieve is the "Plansifter" in which the cocoa passes through four circular horizontal screens.

A handy device for testing the efficiency of sifting equipment consists of a set of sieves arranged horizontally on a tripod. It is mechanically operated on the lines of the Plansifter and is capable of dealing with a charge of 100 grams.[25]

(2) WIND SIFTING

This method is finding increasing favour and it avoids some of the disadvantages encountered when cocoa is sifted through gauze, such as blocking of pores by melted fat and swelling of particles through moisture absorption. Advantages claimed for the installation are maintenance of color and more rapid output.

On entering the plant, the powder is evenly distributed before

[25] Anon., *Gordian, 45,* No. 1078, 18 (1939).

reaching the actual sifting chamber where the finer particles meet a regulated and continuous current of cooled air and are borne through an outlet, whilst the tailings are returned for re-grinding. A final sifting through fine metal gauze removes any fluff picked up by the press cake from cloth filter pads.

C. CARTONING

The sifted powder is conveyed to the packing machine where it is delivered from a chute into paper or cellophane bags, enclosed in cartons or tins. Large containers are placed on a shaking table to assist filling. For small packages the machine is regulated to give controlled delivery of the correct weight. Some machines will show an output of as much as two tons of quarter-pound packages in eight hours.

The lining for the tin should be carefully selected, as taint is all too readily picked up by cocoa powder. For this reason, tins are preferable to cartons as an insurance against spoilage through close proximity of other goods, such as soap, on the grocer's shelf.

D. COCOA POWDER. DEFINITION, GRADES, COMPOSITION

From the foregoing outline of the manufacturing process, it has been shown that cocoa powder consists of ground cacao nibs from which a portion of the fat has been expressed and to which a small amount of aromatic substance has been added, for the purpose of flavouring the product. In addition, alkali is added to "soluble" cocoa.

Three types of cocoa are manufactured in the United States. "Breakfast cocoa" or high fat cocoa, with a minimum fat content of 22% and "cocoa" or medium fat cocoa, containing between 10 and 22% of fat are retailed for domestic use. A product containing less than 10% fat, defined as low fat cocoa, is sold for manufacturing purposes.

Since 1949, under an agreed Code of Practice, the requirements for cocoa retailed in the United Kingdom for drinking are: minimum fat 20%; maximum shell 5%. The only additions permitted are flavouring, salt and alkali. Previously, in the event of a prosecution, it rested with the magistrate to decide whether the article complained of was or was not of the nature, quality and substance expected by the consumer. In the course of a prosecution in 1942, the public analyst for Kingston-upon-Hull maintained that a genuine cocoa should contain a minimum of 20% of fat and supported this contention by

analyses of seventeen samples of cocoa purchased in the district. His opinion was upheld by the magistrate. The composition and degree of refinement of the cocoa samples together with their retail prices are presented in Table XXIV.[26] It is of interest to note that price and quality do not always run parallel.

The amount of fat present influences the colour of the powder. Cocoa with a high fat content presents a richer and darker appearance

TABLE XXIV. Composition of Commercial Cocoa Sold in Great Britain[a]

Sample no.	Price per pound	Moisture, %	Fat, %	Fibre on dry, fat-free basis, %	Passing through 100-mesh sieve, %
1	1s.6d	5.4	25.9	5.7	94.6
2	1s.2d	5.8	19.2	5.0	93.1
3	1s.6d	7.0	22.2	5.6	97.4
4	1s.6d	5.6	23.8	5.6	93.9
5	1s.6d	5.0	19.7	4.8	93.4
6	1s.4d	8.3	18.3	5.1	90.2
7	1s.8d	3.6	22.6	5.5	92.5
8	1s.0d	5.7	23.1	6.1	92.5
9	1s.6d	5.9	27.7	5.2	94.8
10	1s.4d	6.0	21.3	3.1	96.1
11	1s.8d	4.1	24.6	5.0	96.9
12	1s.0d	6.4	23.3	4.8	91.7
13	1s.8d	5.0	26.2	4.9	91.7
14	1s.6d	4.5	27.4	5.1	94.8
15	1s.0d	4.9	24.6	5.6	95.4
16	1s.8d	5.4	24.5	4.6	96.3
17	1s.4d	5.6	23.4	4.7	85.2

[a] D. J. T. Bagnall, *Analyst*, *67*, 321 (1942).

than that of low fat cocoa. It has been indicated that alkalisation causes darkening of the pigments. From the standpoint that the public might therefore be deceived about the nutritional value of alkalised cocoa, the objections raised by the opponents of alkali treatment are understandable.

E. OPTIONAL INGREDIENTS

The practice of adding some flavouring material to cocoa powder is universal. Under the regulations of the United States Food and

[26] Composition of Commercial Cocoas sold in Great Britain. D. J. T. Bagnall, *Analyst*, *67*, 321 (1942).

Drugs Administration, the presence of such ingredients as well as added alkali must be declared on the label.[27] Similar optional ingredients and label statements to those required for chocolate liquor are valid for each of the three grades of cocoa.

The effects of additions of potassium carbonate on the distribution of mineral constituents of cocoa powder were investigated by Fincke and his results are set out in Table XXV.[28]

McCance and Widdowson[29] report the following average values for mineral constituents of three cocoa powders (mean fat content

TABLE XXV. Mineral Content of Unalkalised and Alkalised Cocoa Powder[a]

	Unalkalised cocoa powder	Cocoa powder 1 part K_2CO_3 to 100 parts chocolate liquor	Cocoa powder 2 parts K_2CO_3 to 100 parts chocolate liquor
Moisture, %.....	5.0	5.0	5.0
Fat, %.....	22.0	22.0	22.0
Ash, %.....	5.26	6.70	8.20
K_2O, mg./100 g. .	1780	2900	4000
Na_2O, mg./100 g.	70	70	70
CaO, mg./100 g..	210	205	200
MgO, mg./100 g.	840	820	800
Fe_2O_3, mg./100 g.	20	20	20
Al_2O_3, mg./100 g.	20	20	20
P_2O_5, mg./100 g..	1780	1750	1700
SO_3, mg./100 g...	155	155	150
Cl, mg./100 g....	50	50	50
SiO_2, mg./100 g..	20	20	20

[a] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.

25.6%, moisture 2.5%) which were alkalised with soda: Na 650, K 534, Ca 51.2, Mg 192, Fe 14.3, Cu 0.71, P 685, and Cl 199 milligrams per 100 grams of cocoa powder. Scott Dodd[30] reported the presence of 46.5 to 83.7 milligrams of boron (as a natural constituent) per 100 grams of cocoa powder. On the other hand, Bertrand and Silberstein[31] found only 7.7 to 14.3 parts per million of boron in cacao.

[27] *Federal Register, 9,* No. 243, 14335 (1944).

[28] Mineral Content of Unalkalised and Alkalised Cocoa Powder. H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.

[29] R. A. McCance and E. M. Widdowson, *Chemical Composition of Foods.* His Majesty's Stationery Office, London, 1942.

[30] A. Scott Dodd, *Analyst, 52,* 461 (1927).

[31] G. Bertrand and L. Silbertstein, *Ann. Agron., 14,* 257 (1944); *Chem. Abstracts, 40,* 2501 (1946).

F. JUDGING THE QUALITY OF COCOA

Apart from the interpretation of chemical analyses, quality may be judged from the appearance and fineness of the cocoa powder and its taste, smell and general behaviour when mixed with hot water. In judging the appearance, richness of colour and lightness of texture are noted. Fineness is assessed by sieving. Bagnall[32] considers the particle size satisfactory when at least 90% of the powder will pass through a sieve with 100 meshes per inch.

To judge flavour and aroma, it is necessary to prepare a sample of the beverage. Like tea tasters, professional cocoa tasters make up a mixture without using sugar and milk. Although the main chocolate characteristics are to be found in the non-fat constituents, fat-soluble components make some contribution to the aroma. The presence of any undesirable feature such as high astringency of products prepared from underfermented beans or the objectionable flavour associated with cocoa made from mouldy beans should be noted. As a matter of routine, the taster observes the quantity of coarse material deposited as sediment which, when abnormally large, may indicate inefficient grinding or the presence of shell and is quite distinct from "creaming" due to precipitation of a finely divided caffeine-polyphenol complex as the mixture cools down. Woodman[33] cites some experiments which serve to demonstrate the influence of temperature on solubility of cocoa. In 44 unalkalised cocoas examined, the average cold water extract was 19.34%. At 65°C., 21.55% and at 100°C., 23.29% was soluble. Mean values for eight "soluble" cocoas were 19.75% in cold water, 21.33% at 65°C. and 24.99% at 100°C.

To prepare cocoa for domestic consumption, Knapp[34] recommends a dry mix of one heaped teaspoonful of both cocoa and sugar for every cup required. Equal parts of milk and water are then brought to the boil and poured on to the mixture in a jug with brisk stirring. The contents are then poured into a saucepan, boiled for one minute and returned to the jug to be whisked vigorously before serving.

G. ADULTERANTS IN COCOA POWDER

Adulteration of cocoa is now comparatively rare and is seldom deliberate. The commonest forms of sophistication hitherto practised

[32] D. J. T. Bagnall, *Analyst, 67,* 321 (1942).
[33] A. G. Woodman, *Food Analysis.* McGraw-Hill, New York and London, 1941.
[34] A. W. Knapp, *Cocoa and Chocolate.* Pitman, London, 1923.

were addition of cacao shell, foreign starch, sugar and excessive amounts of alkali. When testing for purity, it is usual to examine the cocoa for traces of arsenic which may be present if alkali of inferior quality has been used in its manufacture.

H. EXTRANEOUS MATTER

Some cocoa samples examined by Walker and Dalby[35] were found to be highly contaminated. In one sample they reported an alarming total of 1000 insect parts per pound and others contained 216, 100, 45, 18 and 18. Counts for rodent hairs were 144, 45, 27, 27, 27 and 23. More recently, factory control has greatly improved and such high counts are exceptional.

[35] N. H. Walker and G. Dalby, *Cereal Chem., 24,* 283 (1947).

CHAPTER IX

MANUFACTURE OF CHOCOLATE

1. Definition

Chocolate which is moulded into bars for eating or used as a covering for sweetmeats and biscuits is an intimate mixture of finely ground roasted cacao nibs and sugar, in which it is usual to incorporate additional cocoa butter and flavouring, with or without the addition of milk solids and emulsifying agents.

The article marketed as "sweet chocolate" in the United States is more simply described in most European countries by the equivalent word for chocolate. In Great Britain, the name "plain chocolate" serves to distinguish it from milk chocolate.

Sweet chocolate or sweet chocolate coating is defined by the U. S. Food and Drug Administration[1] as the solid or semi-plastic food prepared from chocolate liquor, with or without the addition of cacao fat, sweetened with sucrose or partly refined cane sugar or with mixtures of sucrose and dextrose and/or dried corn syrup. It must contain at least 15% of chocolate liquor. When mixtures of sucrose and dextrose are used in its preparation, the latter may not exceed one-third of the total sugar present, and when mixtures of sucrose and dried corn syrup (containing not less than 56% by weight of reducing sugars on a dry solids basis) are used, not more than a quarter of the total saccharine ingredients may be corn syrup. In mixtures of sucrose, dextrose, and corn syrup, three times the weight of dextrose solids plus four times the weight of corn syrup solids may not exceed the total weight of the solids of all the saccharine ingredients. Sweet chocolate may be flavoured with one or more optional ingredients such as ground spice, ground vanilla beans, any natural food flavouring, ground coffee, ground nutmeats, honey, molasses, brown sugar, maple sugar, dried malted cereal extract, salt, and vanillin, ethyl vanillin, coumarin or

[1] *Federal Register, 9,* No. 243, 14335 (1944).

other artificial food flavouring. It may not contain any ingredient which imitates the flavour of chocolate, milk or butter.

Optional dairy ingredients may be introduced in such quantities that the finished chocolate contains less than 12% by weight of milk constituent solids.

Lecithin or monoglycerides and diglycerides of fat-forming fatty acids in combination with monosodium phosphate or derivatives thereof may be added as emulsifying agents, provided that the quantity does not exceed 0.5% in the finished article.

Label declarations are necessary for flavouring, emulsifying and alkali ingredients.

Bittersweet chocolate must contain at least 35% of chocolate liquor.

Milk chocolate, sweet milk chocolate or milk chocolate coating is defined[2] as the solid or semi-plastic food prepared from chocolate liquor, with or without added cacao fat, and one or more of the optional dairy ingredients listed below with one or more of the saccharine ingredients specified for sweet chocolate. It may be flavoured with one or more of the optional flavouring ingredients and emulsified with one or both of the emulsifying agents specified for sweet chocolate. The maximum amount of emulsifying agent permitted is the same as for sweet chocolate. Label declarations are required for added flavouring, emulsifiers and alkali.

The optional dairy ingredients permitted are milk, concentrated milk, evaporated milk, sweetened condensed milk, dried milk, butter, milk fat, cream, skim milk and non-fat dry milk solids. In any ingredient or combination of ingredients used, the weight of non-fat milk solids may not be more than 2.43 times nor less than 1.20 times the weight of milk fat therein. The finished milk chocolate may contain not less than 3.66% of milk fat, 12% milk solids and 10% by weight of chocolate liquor exclusive of alkali.

Skim milk chocolate or coating may contain not less than 12% of skim milk solids and not more than 3.66% by weight of milk fat.[3] Similar limits are specified for buttermilk chocolate or coating and mixed dairy product chocolates.

Chocolate-flavoured coatings prepared with lower melting vegetable fats or hydrogenated vegetable fats other than cocoa butter are

[2] *Federal Register*, 9, No. 243, 14336 (1944).
[3] *Ibid.*

marketed for use in the ice cream industry. Ice cream coating must conform to the requirements for sweet chocolate in all other particulars, except that the limit of 12% of milk solids does not apply. Coatings for use in warm climates may be prepared with higher melting fats and are required to contain at least 6.8% of non-fat cacao matter, which is usually introduced in the form of low fat cocoa.[4]

2. Mixing

Apart from differences in roasting temperatures, processing for the preparation of cocoa and chocolate is generally identical up to the nib stage. It has been noted that vacuum-drying is sometimes used instead of roasting for the preparation of nibs for chocolate-making.

Two different techniques are used for mixing. By the older method, known as the "fine ingredient" process, the sugar and nibs are milled separately before mixing. The alternative practice of incorporating cacao nibs and granulated sugar by grinding them together is advantageous in that the hard crystals of coarse sugar assist in the breakdown of nib tissues. The economy gained by omitting the milling process is partly offset by the longer period of treatment required for subsequent refining.

A. FINE INGREDIENT PROCESS

Unalkalised or alkalised chocolate liquor (cacao mass) may be used for chocolate manufacture, though the former is the more usual ingredient. The sugar should be highly refined, showing 99.8% of sucrose by polarisation. Sugars having a moisture content between 0.02 to 0.01%, mineral matter from 0.006 to 0.03% and invert sugar from 0.03 to 0.2% are recommended by Jensen[5] as being satisfactory. It is important to select a fine-running type of sugar for grinding; too soft a grade will not pass through the machine owing to its tendency to stickiness.[6]

A kek mill is suitable for sugar grinding. In this type of machine, the sugar is ground between two horizontal discs studded with fine steel pins. The upper disc is stationary and the lower one ro-

[4] *Federal Register, 9,* No. 243, 14337 (1944).
[5] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate, Confectionery and Cocoa.* Churchill, London, 1931.
[6] H. W. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture.* Churchill, London, 1930.

tates at the rate of about 4000 revolutions per minute. A disintegrator gives equally sasitfactory results. Here the sugar is beaten into fine fragments by rods travelling at high speed and is subsequently passed through a fine mesh or an air separator.

The ingredients are weighed off to be mixed, ground and kneaded together. Flavouring is added and sufficient cocoa butter is introduced to facilitate smooth operation. It is not practicable to add the whole of the additional cocoa butter at this stage, otherwise the paste produced will be too thin for subsequent refining. The addition of the remainder is therefore delayed until the conching stage is reached. The sugar is added in two instalments because of the thickening effect it produces on the liquor.

B. MIXING NIBS AND GRANULATED SUGAR

The blended nibs and granulated sugar are weighed off and delivered simultaneously to the mixer. Extra cocoa butter and flavouring are added as in the fine ingredient process. Stroud Jordan[7] calls attention to the fact that spongy sugar requires more fat owing to its larger surface and greater power of absorption, but it possesses the advantage that less grinding is necessary. Nevertheless, a longer run in the melangeur is required for intimate mixing than in the fine ingredient process. Where both processes are used in the same factory, the higher grade chocolate is generally prepared from a nib and crystal mix.

In a critical survey of the efficiency of present day equipment, Koch[7a] contends that it is now possible to achieve equally good flavour development, with less consumption of power, by the fine ingredient process.

C. MELANGEURS

The usual type of machine for chocolate mixing is the chocolate melangeur. The ordinary melangeur is a horizontally revolving cast iron pan with a granite bed upon which two granite rolls rotate. A steam coil placed at the base provides sufficient heat to maintain the cocoa butter in a molten condition. The melangeur is warmed before receiving the charge. Whymper[8] recommends a temperature of 40°C. for the machine and 35°C. for the mixture at the time of introduction.

[7] S. Jordan, *Chocolate Evaluation*. Applied Sugar Laboratories, New York, 1934.
[7a] J. Koch, *Internat. Chocolate Rev.*, *7*, 306 (1952).
[8] R. Whymper, *Cocoa and Chocolate*. 2nd ed., Churchill, London, 1921.

By means of lifting gear, the rolls are adjusted at the beginning of the run so that they are sufficiently elevated to break down any lumps of material. When the paste becomes finer, the rolls are lowered to make contact with the bed. Scrapers are provided to free the paste adhering to the rolls and return it to the pan.

A run of twenty minutes to half an hour will suffice for mixing fine ingredients. Excessive exposure in an open melangeur should be avoided because it provides opportunity for fat oxidation and wastage of volatile flavouring material. The working temperature may range from 49° to 65°C. according to the type of chocolate being prepared.

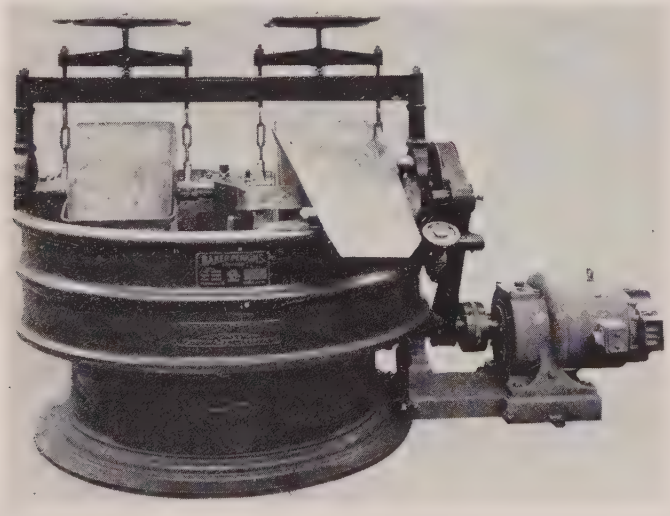


Fig. 26. Chocolate melangeur, showing lifting gear and delivery shute. (By permission of Baker Perkins Ltd., Peterborough, England.)

At the end of the run, the mixture is automatically discharged from the machine illustrated in Fig. 26 by lowering a hinged shute attached to one of the rolls which is capable of being driven independently in the reverse direction. The chocolate picked up on this roll is detached by a scraper and directed down the shute for delivery to the refiner.

The melangeur described above is equally suitable for mixing fine ingredients or nibs and granulated sugar.

In the Bauermeister disc-mill melangeur, measured amounts of nibs and sugar are admitted by two rotary valves and ground between a fixed concave disc and a rotating convex one. On leaving the machine, the warm mixture is fed into the refiner.

D. VACUUM KNEADING MACHINE

A kneading machine may be used instead of a melangeur for the mixing operation. The machine is jacketed, thus permitting the temperature to be regulated either by steam-heating or water-cooling. During two hours' treatment, the chocolate liquor and sugar are worked together at 60° to 70°C. under vacuum. Less cocoa butter is required because the mass becomes more fluid than it would be in an open melangeur. Owing to evaporation of moisture and acid during the kneading treatment, conching time can be shortened. In an open melangeur the sugar will attract moisture unless precautions are taken to regulate humidity. This disadvantage is obviated by using a vacuum kneading machine. Stroud Jordan[9] draws attention to the fact that moisture and air are more readily removed from dense sugar than from spongy sugar.

Kneading machines are said to be particularly suitable for mixing milk chocolate ingredients.

3. Refining

The mixed chocolate paste is usually refined by passage through two sets of rolls. The preliminary refining is done by a sizing machine with three granite or steel rolls which are not water-cooled. The paste is transferred from one roll to the next by setting them at successively increasing speeds. Adjustment depends on the consistency of the mix. The paste passes up the machine and is detached from the top roll by means of a scraper. It may be necessary to place the flaked chocolate in a hot room to bring it to a satisfactory consistency for feeding to the finishing refiner, usually a five-roll machine (Fig. 27). The water-cooled rolls rotate more rapidly than those of the first refiner and operate on the same system of successively increasing speeds.

By the time the chocolate has reached the uppermost roll it should have been transformed into a light powdery material unless the rolls have been set too close together, in which case the fatty portion

[9] S. Jordan, *Chocolate Evaluation*. Applied Sugar Laboratories, New York, 1934.

passes through more freely, leaving solid matter behind. A second refining is necessary for securing uniformity. Humidity control is desirable owing to the increased surface of the sugar particles as refining proceeds.

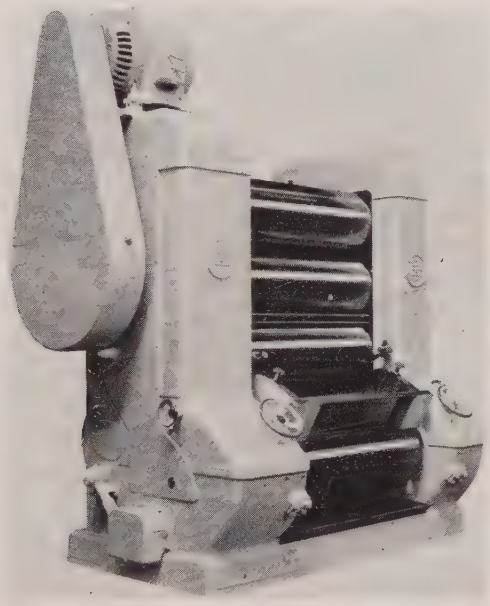


Fig. 27. Five-roll chocolate refiner. (By permission of Baker Perkins Ltd., Peterborough, England.)

Fincke[10] explains the powdery appearance of refined chocolate as being only partly due to the increase in sugar surface. Contributory causes are connected with aeration and incomplete "wetting" of the particles by fat. He draws attention to the fact that sticky sugar becomes fat repellant and therefore, after fracture of the particles, the fat does not immediately form a film on the newly exposed surface. Adhesive forces come into play, owing to pressure by the rolls, and there is a tendency for the sugar to form aggregates which are later broken down in the conche.

By efficient refining, the dimensions of the sugar particles are reduced to between 30 and 25 microns or even smaller size. The powdered chocolate is removed from the top roll by means of a scraper and

[10] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.

is conveyed to the hot room where it is stoved until its condition is sufficiently soft for introduction into the conche.

4. Conching

Conching is an important process designed to improve the flavour and texture of chocolate. The quality and price of the finished product are dependent on the duration of the treatment.

During this process, the remainder of the additional cocoa butter required is mixed with the refined chocolate. It is more economical to delay the introduction of flavouring material until the conching stage is reached and thus avoid the likelihood of loss by volatilisation during exposure in an open melangeur.

A. ADDITION OF EMULSIFIERS

When lecithin or commercial preparations of monoglycerides or diglycerides of stearic and palmitic acids are used, the addition is made towards the end of the conching period.

Lecithin acts as a hydrophilic colloid towards fats and lowers their viscosity and surface tension. Lefevre-Lebeau[11] recommends its use in the chocolate industry for ensuring smoothness and homogeneity. It extends the range of working temperature and increases shelf life. By acting as a wetting agent, it improves the emulsifying power of the fat and when it is present to the extent of 0.3%, a saving of 3% of cocoa butter is effected. An economy results from the use of lecithin in chocolate covering, as more centres can be coated with a given amount of material. It also endows the chocolate with an increased power of adhering to the centre.[12] Its presence is beneficial in arresting the formation of films of moisture which cause sugar bloom after chocolates have been stored in a humid atmosphere.

The principal sources of lecithin are egg yolk, oilseeds and nuts. The soya bean is the chief source of commercial lecithin, the greater part of which is present in combination with protein and carbohydrate; only a small quantity occurs as free lecithin in the oil. The commercial product is a yellow waxlike substance containing 30–35% of lecithin, 4–6% of moisture, 35–40% of soya bean oil and the remainder consists mainly of carbohydrates extracted during manufacture, and cephalin, a colamine base. The crude oil present protects the

[11] Y. Lefevre-Lebeau, *Bull. Officiel de l'Office Internat. du Cacao et du Chocolat, 4,* 333 (1934).

[12] S. Jordan, *Chocolate Evaluation.* Applied Sugar Laboratories, New York, 1934.

phosphatides from oxidation. The defatted substance readily oxidises owing to the high proportion of unsaturated acid groups, including linolenic, present.[13]

Monoglycerides and diglycerides of fat-forming fatty acids are manufactured by a process of interesterification.[14] Such emulsifiers may be used for chocolate-making in the United States in combination with monosodium phosphate derivatives. Edible vegetable fat carriers may be used for either type of emulsifying agent in the United States, provided that the mixture contains not less than 60% of the emulsifying agent.

Alikonis and Farrell[14a] investigated the suitability of several new types of emulsifiers in the development of stable chocolate coatings containing hydrogenated coconut fat (m.p. 110–114°F.) for use in warm climates. Shelf life and palatability were improved by the incorporation of 1% of a mixture of equal parts of sorbitan monostearate and polyoxyethylene sorbitan monostearate. The emulsifiers also prevented the coatings from adhering to the wrappers.

B. METHODS OF CONCHING

The products obtained by using low-roast beans and prolonged conching treatment are superior to chocolates made from more strongly roasted beans and given a shorter conching.

The conche is so-called on account of the shell-like (conchoidal) appearance of the tank in its original form. The function of the machine is to smooth the surface of the solid particles and to effect their complete emulsification with the liquid fat. The sugar particles are only partially coated during refining and the correct texture is developed by ensuring that the fat is thoroughly distributed over the entire surface of the solid matter. Some moisture is evaporated and flavor is enhanced partly by tannin changes consequent on aeration and likewise through removal of undesirable volatile constituents. Thus the machine is designed to combine the processes of mixing, emulsification and aeration and must be capable of sufficient grinding to separate adhering sugar particles and possibly to round off their edges.

[13] A. A. Horvath, *The Soybean Industry.* Spon, London, 1938.
[14] M. B. Jacobs, *Synthetic Food Adjuncts.* Van Nostrand, New York, 1947.
[14a] J. J. Alikonis and K. T. Farrell, *Food Technol., 5,* 288 (1951).

(1) LONGITUDINAL CONCHE

Many types of conches have been perfected, but the longitudinal form of covered tank with curved granite bed and granite roller still holds the field for producing the finest results. The tanks or "pots" are water-jacketed and heat is supplied by means of steam. Such conches are built in units of two or four pots. A large four-pot conche is capable of dealing with a charge of three tons of chocolate. Smaller conches are preferred by some users in the belief that they yield a superior product.

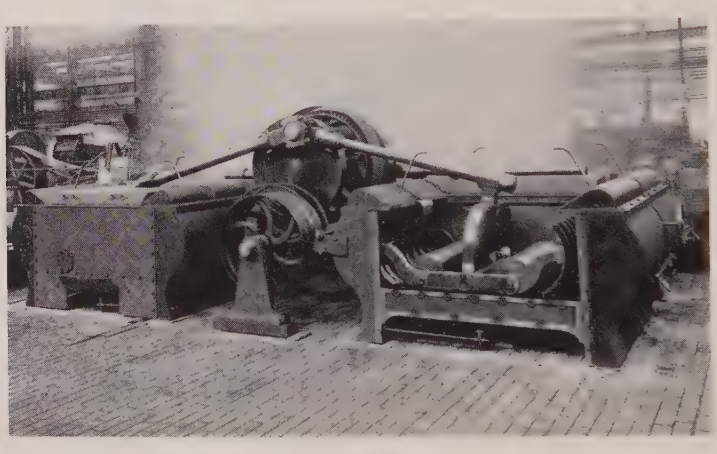


Fig. 28. Four-pot conche machine. The side of one of the pots has been removed to show the rollers and rakes. (By permission of Baker Perkins Ltd., Peterborough, England.)

A crank-driven roller moves slowly to and fro over the bed of the conche at the rate of about 45 strokes a minute and slaps the mixture about. The roller may be equipped with rakes for assisting the turnover of the mixture (Fig. 28).

The conche is warmed up to receive the charge of softened chocolate which is admitted at about 54°C. Further heat is then applied until the desired temperature is attained. This depends on the period of treatment and the type of chocolate being made. Bywaters[15] considers that 80°C. is a satisfactory working temperature for bitter-sweet

[15] H. W. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture*. Churchill, London, 1930.

chocolate. The general range is from 70° to 90°C. for types which contain no milk solids. Lower temperatures, 43–59°C., are the rule for milk chocolate and the speed of operation is slower. The same conditions apply when nut stearin fats are used, by reason of their readiness to oxidise.

For all but the most exacting palates, a run of two to three days in the conche will suffice to produce a satisfactory chocolate. For the highest grade of Swiss chocolate, conching is carried on for four or five days. Beyond that time, deterioration of flavor, possibly caused by over-caramelisation of the sugar, may be detected. A very slight caramelisation is considered to contribute favourably to the flavour. There is little likelihood of material alteration taking place unless the temperature is allowed to exceed 100°C.

The conche is allowed to cool down before the chocolate is discharged. The cooling of such a large bulk may have an important bearing on the mode of fat crystallisation, both from the point of appearance and texture. Aasted[16] offers an explanation of the effect produced on the tongue by correctly conched chocolate. He surmises that during cooling in the conche, the solid particles become partially coated by crystals of the higher-melting glycerides, which do not return to the liquid state on later treatment in the hot room and tempering kettle. These glycerides are subsequently surrounded by an envelope of the lower-melting fraction of the fat, which lubricates the particles as they melt in the mouth, causing them to give up their taste slowly.

(2) ROTATION CONCHE

Designed for reducing the time of treatment, this form of conche achieves intimate mixing by means of a rotary stirrer which causes movement in a horizontal plane, accompanied by a kneading action in a vertical plane. Rotation conches are used with or without application of vacuum. The work is carried out in two stages, the first for elimination of moisture and air and the second for emulsification.

(3) VACUUM CONCHES

By conching in vacuum, the time is considerably shortened. The claim that only ten hours' treatment is required in the Petzholdt

[16] K. Aasted, *Studier over Concheringsprocessen.* Dyva and Jeppesens, Copenhagen, 1941.

vacuum rotation conche, does not appear to have been substantiated in actual practice. In a report on German chocolate machinery[17] it is stated that one factory gave sixteen to twenty four hours' working treatment at 60°C. and another eighteen to twenty four hours' at 70°C.

The Lehmann vacuum conche consists of a large cylindical drum which turns on a horizontal axis. It has the advantage of being capable of dealing with chocolate powder straight from the refiner and is suited to the manufacture of cheaper lines of chocolate. The processing time is only about eight hours at 60°C.

One of the advantages of vacuum conching is that the desired texture may be attained at a lower level of superfatting. The excess moisture and volatile acids are evaporated in minimum time and deaeration of the chocolate is ensured. The speedy withdrawal of air prevents certain desirable transformations of the tannin constituents taking place, hence the product will be more astringent and also lack the full aroma developed by treatment over a long period in the longitudinal conche.

(4) HIGH-FREQUENCY CONCHE

A conching apparatus has been patented by Nordenskjold and Holmquist[18] in which the chocolate is subjected to high-frequency vibrations (about 15,000 per second) with or without injection of a wide range of gases.

(5) THE AASTED METHOD

Aasted[19] claims that the conche designed by him will perform in two hours the work of a longitudinal conche running for three days. The machine can be adapted for use with or without vacuum treatment and also by aeration with air or nitrogen. This covered conche consists of two concentric cylindrical tanks surrounded by a water jacket and is traversed by a centrally-placed axle bearing two discs. The upper one rotates in the inner tank and the lower one, placed at the base of the outer tank, bears projections which occupy the space

[17] *German Chocolate, Cocoa and Confectionery Layout.* British Intelligence Objectives Sub-Committee Report No. 1077. His Majesty's Stationery Office, London, 1946.

[18] British Patent 568,771. 29.9.1943. *Brit. Abs. BIII*, 175 (1945).

[19] K. Aasted, *Studier over Concheringsprocessen.* Dyva and Jeppesens, Copenhagen, 1940.

between a number of jets for admission of air. By setting the axle to rotate at high speed, chocolate introduced into the outer tank is forced into the inner tank and as it travels downwards to return to the outer tank, it is agitated by the disc. The chocolate alternates between the two tanks while being subjected to continuous motion with or without aeration.

C. CHANGES DURING CONCHING

Without doubt, conching has an important influence on the flavour and texture of the finished chocolate. The coarser particles undergo refinement and sugar aggregates are dispersed, but the smaller fragments, if altered at all, are merely rounded off. Bywaters[20] was unable to find any confirmatory evidence of this from microscopical examination of the sugar particles.

Homogeneity is attained by the complete distribution of solid particles in the molten fat. Owing to expulsion of some of the moisture from the mixture, viscosity is lowered at first, but later shows a rise on account of reduction in the size of particles, with consequent increase in surface area. A finely-ground chocolate requires more additional fat than a coarser one for complete envelopment of the solid phase. Fincke[21] has indicated that there are ten million particles (sugar and cacao), with a total surface area of 1000 sq. cm., in one gram of coarsely ground chocolate and a thousand million particles, surface area 5000 sq. cm., in one gram of highly refined chocolate. The latter degree of refinement does not however require the presence of five times the amount of fat as the former, because the interspace is smaller when the particles are finer.

Chemical changes due to conching are not as yet completely understood. Aasted[22] has followed the changes in moisture content, pH, volatile and total soluble acid, water-soluble protein and pigments of chocolate during three days' treatment in a longitudinal conche and short periods in a conche of his own construction with and without vacuum treatment and under aeration with air and nitrogen. The moisture content and pH were determined on aqueous extracts. The

[20] H. W. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture.* Churchill, London, 1930.

[21] H. Fincke, *Appendix to British Intelligence Objectives Sub-Committee. Report No. 57, Item No. 22.* His Majesty's Stationery Office, London, 1946.

[22] K. Aasted, *Studier over Concheringsprocessen.* Dyva and Jeppesens, Copenhagen, 1940.

TABLE XXVI. CHANGES DURING TREATMENT IN LONGITUDINAL CONCHE[a]

Time in hours	A[b]				B[c]				C[d]				D[e]			
	0	24	48	72	0	24	48	72	0	24	48	72	0	24	48	72
Moisture % of chocolate..	0.78	0.57	0.42	0.38	0.82	0.61	0.50	0.42	0.88	0.70	0.55	0.44	0.78	0.61	0.50	0.41
pH of chocolate.....	4.9	5.6	5.7	5.7	5.30	5.50	5.60	5.70	5.5	5.5	—	5.7	5.6	5.6	5.7	5.75
Volatile acid, ml. *N* NaOH per 100 g. nibs.....	1.24	1.04	0.92	0.82	1.48	1.32	1.18	0.96	2.96	2.40	2.20	2.04	1.55	1.43	1.33	1.26
Total acid, ml. *N* NaOH per 100 g. nibs.....	10.00	9.48	9.20	9.00	9.60	8.72	7.36	6.00	10.92	10.80	10.72	10.64	10.00	9.24	8.76	8.72
Pigment 1, % on nibs....	1.89	1.75	1.58	1.41	2.25	2.02	1.80	1.60	1.73	1.48	1.37	1.34	1.83	1.52	1.40	1.37
Pigment 2, % on nibs....	2.47	2.28	2.21	1.83	2.33	2.19	1.93	1.81	2.14	1.77	1.47	1.45	2.54	2.04	1.72	1.68
Pigment 3, % on nibs...	1.76	1.67	1.46	1.29	1.28	1.33	1.39	1.39	0.79	0.96	1.05	0.88	0.76	1.04	1.27	1.02
Soluble protein, % on nibs	3.60	3.20	3.00	2.80	3.70	3.30	3.10	2.90	4.30	3.90	3.50	3.20	4.70	4.50	4.00	3.40

[a] K. Aasted, *Studier over Concheringsprocessen*. Dyva and Jeppesens, Copenhagen, 1941.
[b] A composition: 50% cacao mass, 47% sugar, 3% cocoa butter.
[c] B composition: 50% cacao mass, 50% sugar.
[d] C composition: 50% cacao mass, 45% sugar, 5% cocoa butter.
[e] D composition: 42% cacao mass, 47% sugar, 10.5% cocoa butter, 0.5% lecithin.

pigments were precipitated by cinchonine sulphate and isolated in the following manner:

Pigment 1, which Aasted claims to have identified as quercetin, is obtained by leaching the cinchonine precipitate with hot ethyl alcohol. The orange-coloured solution obtained becomes pale yellow on addition of alcoholic hydrochloric acid or caustic soda and red when reduced by magnesium and hydrochloric acid.

Pigment 2, believed to be cacao brown or a closely allied substance, is extracted as a deep purple solution by treating the cinchonine precipitate with hot hydrochloric acid. The solution turns green on the addition of excess of alcoholic caustic soda. On standing, a light brown precipitate is deposited which dissolves as a reddish brown solution in hydrochloric acid. The pigment thus produced appears to be similar to pigment 3.

Pigment 3 is obtained by dissolving the remaining fraction of the cinchonine precipitate in caustic soda. The red-brown solution changes to yellow on acidification with hydrochloric acid and a red-brown precipitate is deposited which is soluble in caustic soda. Aasted speculates that it consists of one or more substances resembling paeonidin.

The three pigments are sensitive to pH changes and their solubilities are influenced by changes in acidity. Aasted suggests that oxalic acid is mainly responsible for pigment changes during conching.

The changes which occur during three days' treatment in a longitudinal conche at 90°C. are shown for four different recipes in Table XXVI.[23] In all cases, the moisture content is reduced to approximately half of its original level. Between one-third and one-fifth of the volatile acid disappears. The decrease in total acid is apparently due to solubility effects as well as volatilisation. About a quarter of the protein is rendered insoluble by the end of the run. In every case Pigments 1 and 2 decreased. In the first experiment only, Pigment 3 decreased. In all other cases a slight increase occurred.

Different trends in the concentration changes were observed on varying the conditions of treatment for runs of two hours in Aasted's model conche. When the vacuum method was used, an increase in total soluble acid and protein occurred. The concentrations of Pigment 1 and Pigment 3 increased, but Pigment 2 decreased.

[23] K. Aasted, *Studier over Concheringsprocessen.* Dyva and Jeppesens, Copenhagen, 1940.

Under atmospheric pressure, the volatile acid concentration was practically constant, but there was a marked rise in total soluble acid content. Pigment 1 increased by almost 50% of the original amount, Pigment 2 decreased slightly and Pigment 3 showed a trifling increase. Protein solubility also increased.

During a run with injection of air, volatile acidity rose slightly and total soluble acidity decreased. Pigment 1 showed a maximum concentration at the end of one hour and returned to its original value in two hours. Pigment 2 behaved similarly and Pigment 3 increased and then fell to slightly below its original level. Under nitrogen aeration, volatile acid increased after one hour and then decreased and total soluble acid rose markedly. The amounts of pigments and protein in solution rose at first but their concentration was lower at the end of the run.

5. Milk Chocolate Manufacture

Milk chocolate is prepared by mixing condensed milk or dried milk with chocolate liquor and sugar. Some manufacturers consider that a mixture of dry skim milk and butter, in proportions normally occurring in whole milk, produces a better flavour than dried whole milk. It is generally acknowledged that the best results are obtained with condensed milk. It imparts a smooth velvety texture to the chocolate and may retain larger amounts of vitamins than are likely to survive the processing for dried milk.

Condensed milk is prepared by adding sugar to fresh milk and concentrating the mixture in vacuum pans until the required consistency is reached. In some chocolate factories, condensed milk is prepared on the spot for immediate use. Smaller undertakings without the necessary plant make use of ready-made condensed milk.

When condensed milk is poured into a melangeur containing warm chocolate liquor, the mixture thickens owing to the presence of moisture in the milk. After the mixing, excess moisture can be removed by vacuum treatment in a covered melangeur or in a vacuum kneading machine. If an open melangeur has been used, the mixed chocolate is spread on trays and dried on steam-heated shelves in a vacuum chamber.

When dried milk is used, the ingredients may be incorporated in a melangeur or vacuum kneading machine.

Apart from the lower working temperatures desirable for milk

chocolate, subsequent treatment is the same as for ordinary sweet chocolate.

6. The McIntyre Rapid Method of Chocolate Manufacture

The McIntyre chocolate machine is designed to combine all the processes from the nib stage to the end of the conching period. It consists of a horizontal cylinder having a fluted inner surface through which passes a central rotating shaft with a number of beaters attached. These bear down on the flutes and exert a grinding and mixing action on the charges of nibs and sugar which are admitted through a hopper at one end of the cylinder. A fan placed at the opposite end aerates the mixture. Additional cocoa butter is introduced in small lumps or in molten form. The machine is capable of dealing with a half-ton batch and sixteen hours' treatment is required to produce a high degree of refinement.

7. Tempering

The conched chocolate is stoved in the hot room prior to being tempered. The aim of tempering is to condition the chocolate until it is in the ideal physical state for deposition into moulds or for coating centres. By continuous agitation of the slightly supercooled fat, sufficient seed is established to regulate the formation of stable fat crystals and to ensure that the finished article will retain a satisfactory appearance throughout its shelf life. During carefully regulated tempering, crystallisation of about 3% of the total fat takes place. Unless this condition is satisfied, the eventual growth of stable crystals is uncertain.

A. TEMPERING KETTLE

The vessel in which the chocolate is cooled down to and maintained at the desired temperature for admission to the enrober tank is known as a tempering kettle. It has a fixed water-cooled bed and is equipped with stirring gear. In the Baker-Perkins model illustrated, two discoid stirrers are used for keeping the mixture in motion. The capacity of this machine is 600 lb. Larger kettles will accommodate about 10 cwt. (Fig. 29).

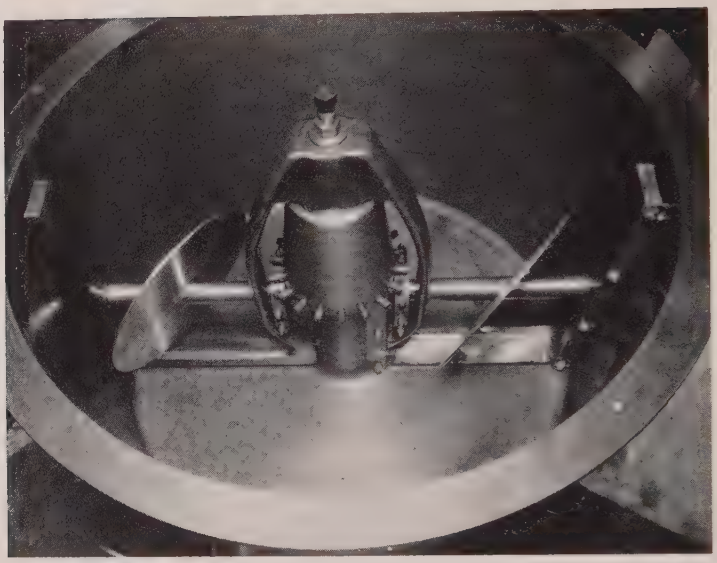


Fig. 29. Chocolate tempering kettle with two discoid stirrers. (By permission of Baker Perkins Ltd., Peterborough, England.)

The mixture is maintained in a state of continual motion to prevent settling of solid particles and to assist in the expulsion of air bubbles which would cause cavities on the surface of moulded tablets. The chocolate is maintained in a fluid condition until required for deposition into moulds or for covering.

B. TEMPERING TECHNIQUE

Freundlich[24] has elaborated two methods which give good results for coated lines. The chocolate may be cooled down to 30°C. (86°F.) or even lower until the consistency is mushy. The temperature is then raised to 33°C. (91.4°F.) which is maintained until the mixture acquires the desired fluidity. For sweet chocolate 32° to 33°C. and for milk chocolate 30–31°C. (on account of the butter fat present) should give satisfactory results. Alternatively, chocolate is cooled to the actual temperature at which it is to be used and stirring is continued for at least one hour, until the temper is judged to be satis-

[24] L. Freundlich, *Manuf. Confectioner, 26,* No. 6, 46A (1946).

factory. Addition of chocolate shavings to chocolate tempered at 33°C. is recommended to facilitate crystallisation. Freundlich warns against stirring after the correct temper has been attained and advises that just sufficient chocolate be tempered at a time to charge the coater tank of the enrober. The process can be made continuous by using two kettles in series. As the fully tempered chocolate in the first kettle flows to the enrober tank, it is replaced by molten chocolate from the second kettle. Thus the tendency for the chocolate to become over-tempered is counterbalanced by the continuous flow of undertempered chocolate and the ideal temper is maintained throughout the run.

The temper may be determined by the use of a metal bob of known weight suspended on a wire. It is first dipped to a mark on the wire in untempered chocolate and weighed after draining. The operation is then repeated with tempered chocolate. The degree of temper can then be calculated by dividing the weight of untempered chocolate remaining on the bob by the weight of untempered chocolate similarly retained.

Easton, Kelly and Bartron[24a] have established a relationship between the degree of temper and the shape and slope of curves obtained by measuring the cooling rates of molten chocolate or cocoa butter in air maintained at —70°C. Results indicate that the effect being measured is solely that of fat crystallisation.

Whymper[25] favours automatic control to standardise the tempering and setting of chocolate rather than seeding with chocolate.

8. Moulding of Chocolate Tablets

Highly polished metal moulds are warmed up to the same temperature as the tempered chocolate which they are to receive. They travel in rows along a conveyor and, as they pass beneath the depositing tank, an exact weight of chocolate is forced into each tin. As the tins proceed towards the cooling tunnel, they are subjected to mechanical shaking for liberation of any air bubbles.

The time of passage through the tunnel is regulated according to the size of the unit. The tablets proceed into the cooling tunnel against a current of air cooled by passing over pipes containing brine. When they emerge, the chocolate is firmly set and should have a high gloss if the right cooling conditions have been fulfilled. Efficient tempering is a prerequisite for success. Gloss is influenced also by particle size.

[24a] N. R. Easton, D. J. Kelly and L. R. Bartron, *Food Technol., 5,* 521 (1951).
[25] R. Whymper, *Internat. Confectioner,* Reprint p. 35 (June 1948).

In modern machines, the chocolate is dislodged mechanically by inverting the mould and the tablets are conveyed through cooled air towards the wrapping machine. The moulds travel in the reverse direction to be warmed up to receive the next batch of chocolate.

If the chocolate entering the cooling tunnel encounters too cold a blast of air, solidification will be too sudden and supercooling will cause the formation of a hard outer shell. The chocolate will then be in an unstable state owing to delay in removing latent heat from the interior of the bar.

To permit the formation of a matrix of stable crystalline fat about which the remainder of the fat can crystallise, cooling of properly tempered chocolate should be gradual until the bar is almost solid. The crystallisation may then proceed safely at a lower temperature and is completed during cold storage. Meeker[26] postulates the ideal conditions for establishment of a stable state as 50% crystallisation when the chocolate is halfway through the tunnel, 80 to 90% on discharge and 90 to 100% under storage. He therefore recommends the use of a cooling tunnel divided into two sections by a baffle plate. In the first half, the temperature is between 15.5° and 18.3°C. (60–65°F.), to allow formation of the matrix and avoid undue supercooling. In the second section, the tablets meet a high velocity air current from 4.5 to 10°C. (40–50°F.), for optimum heat transfer. The bottom of the conveyor belt should also be cooled. After leaving the tunnel, the chocolate should be stored for 12 hours at 15.5° to 21°C. (60–70°F.).

9. Covering Chocolate Confectionery (Enrobing)

A multitude of chocolate-coated sweetmeats is on the market today. A box of assorted varieties may include centres made of chopped nuts, fruits, fondant creams, caramel, hard toffee, nougat, fruit syrups and even liqueurs. Solid or cream centres are generally deposited in starch moulds. They may be coated with chocolate by hand dipping or by mechanical means. Liquid centres are injected into chocolate shells through a narrow opening which is finally closed with a spot of melted chocolate.

Hand coating is generally done by placing the centre on a fork and dipping it in a vessel containing tempered chocolate. The bonbon is then withdrawn and if a pattern is required, the necessary scroll work is piped on or worked up with the fork. This somewhat tedious method of covering is now used only for luxury lines.

[26] E. W. Meeker, *Manuf. Confectioner, 23,* No. 2, 16; No. 3, 15 (1943).

Centres for enrobing by machinery are arranged in rows on a conveyer of wire netting and carried through a shallow tank of chocolate which coats their bases. The under surface is then cooled to set before the upper surface receives its baptism of chocolate from the enrober tank. In another type of machine, the operations of covering the top and bottom of the centre take place simultaneously. Excess of chocolate is removed by a draught from a fan and returned to the tank for further use. The chocolates pass under a decorating device where a pattern is imprinted on them.

Unless the centres are at almost the same temperature as the tempered coating, gloss will be reduced either through supercooling, or, if the centre is too warm, on account of disturbance of the temper.

Freundlich[27] recommends the following temperature ranges. Enrober room 21° to 26.6°C. (70 to 80°F.), centres 18.3° to 23°C. (65° to 75°F.), cooling tunnel 7.2° to 13°C. (45° to 55°F.), and packing and storage at 18.3° to 21°C. (65° to 70°F.). In summertime when enrober room temperatures are higher, the distance between the depositor and cooling tunnel should be reduced. For best gloss, the temperature of the cooling tunnel requires to be modified as the room temperature changes.

Bywaters[28] advises 23°C. (75°F.) for the enrober room, 23° to 26.6°C. (75° to 80°F.) for centres, 32.2°C. (90°F.) for enrober tank and gives a timely warning against keeping the chocolates too long in a cooling tunnel at 10°C. (50°F.), in which case the covering may later become coated with a film of moisture through being at a temperature below the dew point of the packing room. Ideal conditions for the packing room are temperature 18.3°C. (65°F.) and relative humidity 60%.

In the Winkler and Dunnebier covering machine of German make, the operations of tempering and enrobing are combined in a single machine which makes use of a tempering worm and does not therefore require to be fed with pre-tempered chocolate.

Chocolate coating is also used for cake decoration and covering fancy biscuits, ice cream bars, pills and medicinal tablets. Sometimes, as in the preparation of laxative tablets, chocolate and the medicinal ingredient (usually phenolphthalein) are intimately mixed and cast into small units.

[27] L. Freundlich, *Manuf. Confectioner, 26,* No. 6, 46A (1946).

[28] H. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture*, Churchill, London, 1930.

10. Wrapping

For their protection, chocolate tablets are encased in two or three wrappers. These may consist of metal foil, waxed paper and an outer paper of attractive appearance. The tinfoil of former years has been superseded by aluminum. Waxed paper affords some protection against humidity changes. Waterproof cellophane is also largely used. The task of applying all the wraps is often accomplished by a single machine with an astonishingly high output.

Boxes of fancy chocolates are packed by hand. All the packaging material should be reasonably dry. Bywaters gives 10% as the limit of safety for moisture content.

11. Defects Occurring during Storage

A. FAT BLOOM

Fat bloom is manifested in several different forms and except where temperatures during transit and storage are sufficiently high to cause liquefaction of the cocoa butter, it originates through wrong temperature conditions during tempering, depositing or subsequent cooling operations.

If chocolate is deposited at too high a temperature, the fat crystallises in streaks owing to the lack of a regular matrix of seed crystals. When the chocolate is allowed to cool too slowly during tempering and is insufficiently stirred, the formation of groups of crystals will be encouraged and they will develop as surface spots. The appearance of a white bloom uniformly distributed over the entire surface arises through too sudden chilling after deposition. This leads to an unstable vitreous condition and subsequent growth of fine fat crystals which, when examined with a hand lens, are seen to project from the surface of the goods. Another cause of fat bloom is due to oil exudations from nutty centres. The oil becomes a solvent for cocoa butter which eventually re-crystallises. Jensen[29] recommends a protective covering between the centre and coating as a cure for this defect.

Machine-covered goods show a greater tendency to bloom than hand-dipped chocolates. The best results are obtained in machine-

[29] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate, Confectionery and Cocoa.* Churchill, London, 1931.

depositing where the technique of hand-dipping is imitated as closely as possible. Thus when chocolate shavings are used for seeding, conditions are similar to those of the hand dipping process where the desired temper is maintained by adding solidified chocolate at intervals to the bulk of molten chocolate. Whymper[30] urges that the art of the human expert should be improved upon rather than merely imitated by automatic control.

Chocolates which exhibit bloom are not rendered unwholesome, but their appearance has an adverse effect on sales. Much attention has therefore been devoted to the causes and prevention of fat bloom. Whymper,[31] who made a notable contribution by his treatise on the subject, was one of the earliest workers in this field.

The time lag for development of fat bloom defects varies according to the precise cause of the trouble and may be as long as one to three months after the goods have left the factory.[32]

The problem of protecting chocolate against unfavourable storage conditions has been approached from two new directions by Easton and co-workers.[32a,32b] Resistance is increased when the cocoa butter is modified by hydrogenation, fractionation or isomerisation. Alternatively, the incorporation of sorbitan monostearate, alone or mixed with polyoxyethylene sorbitan monostearate, has proved highly successful in arresting fat bloom. Results of trials made with commercially prepared dark chocolate demonstrate that the addition of 1% of a 60:40 mixture of the above-mentioned modifiers, with or without added lecithin, provides the most effective protection.

B. SUGAR BLOOM

When chocolate is packed in absorbent materials or exposed directly to moist air, a film of dew is deposited on its surface. If this condition prevails sufficiently long to permit absorption of moisture by the sugar particles, the surface of the chocolate will become sticky and a white incrustation of sugar remains when evaporation takes

[30] R. Whymper, *Internat. Confectioner,* Reprint 25, June (1948).
[31] R. Whymper, *The Problem of Chocolate Fat Bloom.* Manufacturing Confectioner Pub. Co., Chicago, 1933.
[32] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate Confectionery and Cocoa.* Churchill, London, 1931.
[32a] H. A. Neville, N. R. Easton and L. R. Bartron, *Food Technol., 4,* 439 (1950).
[32b] N. R. Easton, D. J. Kelly, L. R. Bartron, S. T. Cross and W. C. Griffin, *Food Technol., 6,* 21 (1952).

place. This defect tends to be aggravated when the sugar particles are finer, unless sufficient fat is present to provide a high degree of surface protection. The chances of condensation taking place on the chocolate surface are increased when the difference in temperature between the cooled chocolates and the packing room is accentuated by unduly slow passage through the cooling tunnel.

Controlling factors for the prevention of sugar bloom are rigid regulation of humidity in the packing room, reduction of the moisture content of packing materials to a safe level prior to wrapping and subsequent storage in a dry atmosphere.

Macara[33] has shown that critical relative humidities for the incidence of sugar bloom are 85% for dark chocolate and 78% for milk chocolate.

C. SUSCEPTIBILITY OF CHOCOLATES TO EXTREMES OF TEMPERATURE

When chocolates displayed in shop windows are exposed to strong sunlight, liquefaction of the fat may cause either fat bloom or sugar bloom. The latter condition arises when the sugar particles lose their protective film of fat and are consequently more susceptible to humidity changes.

D. BURSTING

If fondant centres straight from the cold room are coated with chocolate, bursting may occur in a few hours through expansion. This trouble can be avoided by warming the centre to the same temperature as the coating.

Bursting which occurs after a lapse of two weeks or even longer is caused by gas generated through fermentation of the fondant syrup. This defect is also recognized by the honeycomb appearance of the centre.[34]

Fondant paste consists of a syrup in which minute crystals of sugar are dispersed. Whilst growth of saccharomyces yeasts is inhibited by fairly concentrated syrups, a concentration of 79–80% is needed to check the growth of torula yeasts.[35]

Fondant paste prepared from sucrose alone will not provide the

[33] T. Macara, *Conf. J.*, 809, 845 (1927). Reprint.
[34] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate, Confectionery and Cocoa.* Churchill, London, 1931.
[35] M. Berman, *The How and Why of Candy Making.* Boyles, Chicago, 1925.

necessary resistance, because its saturated solution contains only 67% of soluble solids at ordinary room temperature. Admixture of sucrose with invert sugar or corn syrup will increase the strength of the syrup portion to the safety level of 80% solids. Invert sugar must be used with discretion owing to the relatively low solubility of the dextrose component. Corn syrup, which is a mixture of dextrose, maltose and dextrins allows a little more latitude.

There is little doubt that the organisms are introduced while the fondant is in contact with the moulding starch. Contamination is minimised by proper air conditioning. Wijnoogst[36] recommends a working temperature of 24°C. and relative humidity of 45% for starch and trays, and 24°C. and a relative humidity of 55% for the drying room.

Bursting caused by flaws in the chocolate coating which allow leakage of the centres is distinguished from fermentation defects by the absence of gas formation.

E. MOULD GROWTH

Mould filaments are visible on the chocolate surface when condensation has occurred in a mould-laden atmosphere.

Mould-infected starch is the cause of mould development between the coating and centre of chocolates. As no gas-production occurs, the coating remains intact and it is only when the chocolate is being eaten that the consumer is made aware of the contamination by the musty taste.

Infection can be avoided by taking care that the starch is properly conditioned.

The German firm of Winkler and Dunnebier produced a mogul which eliminates the use of moulding starch.[37] A continuous chain of aluminum moulds is covered with thin rubber sheeting stretched into position by suction. After the creams are deposited the moulds proceed to a drying chamber in which conditioned air is circulated at 35°C. After drying for a period of 20 to 24 minutes, the moulds are inverted and the centres are ejected by the release of the vacuum. In another machine by the same firm, the creams are deposited into rubber moulds for which no vacuum is required.

[36] H. C. J. Wijnoogst. *Hints for Cocoa and Chocolate Manufacture.* 2nd ed., Resultat Verlag, Amsterdam, 1938.

[37] *British Intelligence Objectives Subcommittee Report No. 1115.* German Chocolate and Cocoa Practice. His Majesty's Stationery Office, London, 1946.

F. SPOILAGE DUE TO FRICTION

Unless chocolates are tightly packed, they will not withstand jolting during transit and their surface will lose its gloss and become discoloured by pale scratches.

G. RANCIDITY

Under suitable conditions, cocoa butter withstands prolonged storage much better than coconut and similar seed oils. Chocolates decorated with coconut shaving or nuts have a much shorter shelf life. A quick turnover is therefore desirable for these and likewise for milk chocolate lines.

H. MOTH INFESTATION

When precautions for keeping the factory premises free from moths are inadequate, it sometimes happens that eggs are deposited on the packing materials or even on the chocolate itself in the interval between its emergence from the cooling tunnel and wrapping or packing. During the lapse of time before the goods reach the consumer, the grubs hatch out and the hitherto unsuspected infestation is not discovered until the package is opened. Similar trouble arises when unsound nuts have been used for decorating the chocolates.

12. Chocolate Recipes

When cacao beans are blended, they are selected for flavour, colour, fat content and price. Light-coloured beans from Venezuela, Java and Ceylon and dark-coloured beans from Ecuador, Trinidad and Venezuela are added to improve the flavour of ordinary types from West Africa, Bahia, Sanchez, etc., which supply the bulk of the beans. The following examples selected from a very comprehensive list of recipes by "Cicerone"[38] give some indication of the blends of beans and flavouring materials appropriate for various types of chocolate goods.

Sweet Chocolate Coating

Cacao nibs	Accra (W. Africa)	140 lb.
	Bahia (Brazil)	112 lb.
	Trinidad	80 lb.
Cocoa butter		168 lb.
Raw sugar		10 lb.

[38] "Cicerone," *Confectionery Production, 15,* No. 2; 25 (1935).

Icing Sugar	510 lb.
Vanilla pods	1 1/2 lb.
Coumarin	3/4 oz.

Sweet Chocolate Coating

Cacao nibs Bahia	90 lb.
Arriba (Ecuador)	90 lb.
St. Thomé	90 lb.
Cocoa butter	120 lb.
Icing sugar	360 lb.
Vanillin crystals	4 oz.
Potassium carbonate	8 oz.

Sweet Chocolate

Cacao nibs Trinidad	120 lb.
Arriba	60 lb.
Accra	150 lb.
Cocoa butter	150 lb.
Icing sugar	520 lb.
Milk powder	10 lb.
Nutmeg	1/2 lb.
Vanilla pods	3/4 lb.
Salt	1 1/2 lb.

Milk Chocolate

Cacao nibs Ceylon	50 lb.
Java	25 lb.
Caracas (Venezuela)	30 lb.
Cocoa butter	168 lb.
Icing sugar	300 lb.
Full cream milk powder	88 lb.
Vanillin crystals	4 oz.
Salt	1 lb. 4 1/2 oz.

Dutch Milk Chocolate

Cacao nibs Java	60 lb.
Samoa	40 lb.
Caracas	45 lb.
Cocoa butter	270 lb.
Icing sugar	285 lb.
Full cream milk powder	150 lb.
Skim milk powder	70 lb.
Salt	1 1/2 lb.
Cinnamon	1 1/2 lb.
Vanilla pods	1 1/2 lb.

The following recipes are due to Berman:[39]

Milk Chocolate for Machine Coating

Light liquor	100 lb.
Sugar	100 lb.
Whole milk powder (28% fat)	40 lb.
Cocoa butter	35 lb.

Milk Chocolate for Moulding

Light liquor	35 lb.
Sugar	100 lb.
Whole milk powder (28% fat)	40 lb.
Cocoa butter	35 lb.

Cheap Chocolate for Machine Coating

Blended liquor	200 lb.
Sugar	240 lb.
Cocoa butter	77 lb.
Vanillin crystals	3 oz.

Light Chocolate for Hand Dipping

Light liquor	36 lb.
Sugar	70 lb.
Cocoa butter	16 lb.
Vanilla beans	1 lb.

Jensen[40] gives the following range for sweet chocolate composition:

Nibs	30.5–50%
Sugar	48–52.5%
Cocoa butter	4–19%

Bywaters[41] recommends the following recipe for a good quality milk chocolate:

Chocolate liquor	15 lb.
Sugar	76 lb.
Full cream milk powder	37 lb.
Cocoa butter	36 lb.
Cashew nuts or barcelonas	5 lb.

[39] M. Berman, *The How and Why of Candy Making*. Boyles, Chicago, 1925.
[40] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate Confectionery and Cocoa*. Churchill, London, 1931.
[41] H. W. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture*. Churchill, London, 1930.

When chocolate is fortified with vitamin A from natural sources, a slightly fishy taste is liable to persist. No objectionable flavour is detectable when synthetic vitamin A palmitate is used. Vitamins are conveniently introduced in the form of a premix.

Vitaminised Chocolate

Vitamin A and D concentrate (10 parts of A and 1 part of D)	38 grams
Vitamin B_1	1.84 grams
Vitamin B_2	3.68 grams
Niacin	18.4 grams
Vitamin C	55.2 grams
Molten chocolate	to make 1 lb.

The mixture is then incorporated with 99 lb. of chocolate.

Deterioration during shelf life amounts to 20% of vitamins A and D and 15% of the other vitamins.[42]

The chemical composition and nutritional values of different types of chocolate are discussed in Chapter X, 2 and 3.

[42] A. E. Leighton, *Internat. Chocolate Rev., 6,* 231 (1951).

CHAPTER X

NUTRITIONAL VALUE OF CACAO PRODUCTS

1. Cocoa Powder and Chocolate-flavoured Beverages

The grade of cocoa powder known in the United States as breakfast cocoa contains at least 22% of fat. Products of a similar type are marketed in European countries. By reason of its high fat content, cocoa powder supplies more energy than an equal weight of either tea or coffee.

In addition to their notable contribution to the energy value of foodstuffs, fats provide the fatty acids essential for health and serve as carriers for phospholipids and fat-soluble vitamins. When fat is consumed, it retards digestion and therefore gives satisfaction for a longer period than carbohydrates and proteins. According to Gardner and Fox,[1] cocoa butter is slightly less digestible than butter fat, because its main constituent acids, palmitic, stearic and oleic, are long-chain compounds which are utilised more slowly than the fatty acids of lower molecular weight which occur in comparatively large quantities in butter fat. Linoleic acid, one of the unsaturated acids indispensable to human nutrition is present to the extent of about 2% of the component fatty acids of cocoa butter.[2] Choline, regarded as essential to the mechanism of human metabolism, occurs in the free lecithin which is present in cocoa butter, and also in the form of a lecithin-protein complex in the non-fat portion.

In one ounce of cocoa powder, 14 I. U. of vitamin A (probably as precursor β-carotene), 0.03 mg. of vitamin B_1 (thiamine), 0.08 mg. of vitamin B_2 (riboflavin), 0.3 mg. of vitamin B_5 (nicotinic acid) and no vitamin C (ascorbic acid) have been found.[3] Fincke[4] states that commercial cacao beans do not appear to contain ascorbic acid.

[1] J. A. Gardner and F. W. Fox, *Biochem. J., 13,* 368 (1919).
[2] T. P. Hilditch and W. J. Stainsby, *J. Soc. Chem. Ind.,* 95T (1936).
[3] Anon., *Manual of Nutrition* (Appendix) Ministry of Food, His Majesty's Stationery Office, London, 1945.
[4] H. Fincke, *Kazett, 30,* 130, 142 (1941).

A rough estimate of the protein content of cocoa can be calculated by deducting the nitrogen due to the theobromine and caffeine present from the total nitrogen and multiplying the remainder by 6.25. It is questionable whether more than one-third of the protein in cocoa can be completely utilised. Evidence obtained from feeding tests on young rats led Mitchell, Beadle and Keith[5] to classify cocoa as an unimportant source of protein. According to their findings, the digestibility coefficient of cocoa protein is 38% and its average biological value 37%. The biological value of milk protein is 84%.

The percentage of total carbohydrates in cocoa is frequently reported as a difference figure, consequently its calorific value is likely to be overestimated. A closer approach to the true value is provided by McCance and Widdowson,[6] who base their calculations on the monosaccharide equivalent of the carbohydrates present.

Concerning the availability of iron and phosphorus in cocoa, McCance and Widdowson[7] state that 93% of the total iron and 85% of the total phosphorus are present in an ionisable form. The remaining phosphorus is in the form of phytic acid. Calcium and magnesium phytates are very insoluble and may be precipitated in the duodenum. They are particularly resistant to intestinal attack and are therefore not utilisable.

Mosimann[8] found 0.72 to 1.18% of oxalic acid in fat-free dry cacao nibs from different sources. Until recently, the possibility that these quantities of oxalic acid might exert an adverse effect on the retention of dietary calcium was largely a matter of conjecture. Mitchell and Smith[9] investigated the effects of cocoa as an ingredient in the diets of rats and human beings and confirmed the findings of Mueller and Cooney[10] that the rate of growth was depressed in rats. When the daily dose for humans did not exceed 34.8 grams of cocoa, there was no appreciably adverse effect, despite the fact that there is only sufficient calcium in cocoa to combine with two-thirds of the oxalic acid

[5] H. H. Mitchell, J. R. Beadle and M. H. Keith, *J. Biol. Chem., 71,* 15 (1926).
[6] R. A. McCance and E. M. Widdowson, *Chemical Composition of Foods.* His Majesty's Stationery Office, London, 1942.
[7] R. A. McCance and E. M. Widdowson, *Chemical Composition of Foods.* His Majesty's Stationery Office, London, 1942.
[8] G. Mosimann, *Internat. Choc. Rev., 2,* 186 (1947).
[9] H. H. Mitchell and J. M. Smith, *J. Am. Med. Assoc., 129,* 871 (1945).
[10] W. S. Mueller and M. R. Cooney, *J. Dairy Sci., 26,* 51 (1943); *Chem. Abstracts, 39,* 5291 (1945).

present. This finding bears out Fincke's[11] contention that human beings are able to utilise calcium in the form of oxalate. In support of this, he draws attention to the fact that spinach, which contains a higher percentage of oxalate than is present in cocoa, does not upset the calcium balance of healthy people and concludes that cocoa can be consumed without danger except by those invalids for whom an oxalate-free diet has been prescribed.

Fincke[12] is sceptical concerning the frequently reiterated warnings that cacoa and chocolate, by reason of their high tannin content, are likely to encourage constipation and maintains that this is true only in the case of consumers who already have a tendency in that direction.

On account of the presence of theobromine and caffeine, cocoa and chocolate exert a mild therapeutic action on the nervous system and kidneys. The effects of these bases are similar, though manifested to a lesser degree by theobromine than by caffeine.

According to Hutchinson[13] "caffeine influences the higher psychic centres more than medullary centres and, to a lesser degree, the spinal cord. It is capable of clearing the mind, abolishing sense of fatigue and even of inducing sleeplessness. Stimulus is also provided for the respiratory and cardiac systems. Circulation of the blood is improved and direct action on the kidneys causes diuresis."

The amount of caffeine (about 0.01 gram) in a cup of cocoa is small by comparison with the dose in a cup of tea or coffee. A cup of cocoa contains about 0.1 gram of theobromine. As a safeguard against adverse effects due to excessive intake of theobromine, Fincke[14] suggests that the daily intake of cocoa should be limited to 20 grams for children and 25 grams for adults and recommends 12 grams for children and 18 grams for adults as being safe quantities for consumption at one meal.

In a cup of cocoa containing 125 grams of a beverage mixed in the following proportions:

cocoa powder	4 parts
sugar	4 parts
milk	50 parts
water	42 parts

[11] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[12] *Ibid.*
[13] V. H. Mottram and G. Graham, *Hutchinson's Food and the Principles of Dietetics*. 9th ed., Arnold, London, 1940.
[14] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.

TABLE XXVII. ENERGY VALUE OF MILK, COCOA POWDER AND COCOA PREPARATIONS

	Full cream milk[a]	High-fat cocoa			Medium-fat cocoa[c]	Sweetened milk-cocoa powder[e]		Bournvita[d]	Ovaltine	
		[b]	[c]	[d]					[d]	[f]
Fat, %.....	3.6	26.5	22.0	25.6	12.0	3.6	3.3	7.5	7.9	8.0
Protein, %.....	3.3	22.3	18.0	20.4	20.0	21.0	30.2	11.4	13.2	14.2
Carbohydrate, %....	4.7	31.0	42.0	35.0[g]	47.0	66.8	55.8[h]	67.6[g]	61.6[g]	67.9
Calories per 100 g., %.	66	465	450	452	385	393	383	370	356	411

[a] S. K. Kon, *The Nation's Food* (edited by A. L. Bacharach and T. Rendle). Heffer, Cambridge, England, 1946.
[b] Anon., *Gordian Essays on Cocoa.* Rieck, Hamburg, 1936.
[c] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[d] R. A. McCance and E. M. Widdowson, *Chemical Composition of Foods.* His Majesty's Stationery Office, London, 1942.
[e] Unpublished data by the author.
[f] V. H. Mottram and G. Graham, *Hutchison's Food and the Principles of Dietetics.* 9th ed., Edward Arnold, London, 1940.
[g] Available carbohydrate reckoned as monosaccharide; energy value calculated as 3.75 calories per gram.
[h] Wartime product, sweetened partially with saccharine.

Fincke[15] estimates that there will be 3.1 grams of fat, 10 grams of carbohydrate and 2.75 grams of protein, which together supply a total of 81 calories. By mixing the same proportions of sugar and cocoa with 92 parts of undiluted milk, the energy value is raised to 114 calories.

For consumers who prefer to be spared the trouble of measuring the separate ingredients, many handy preparations containing cocoa, milk and sugar are available for mixing with water. Some of these are marketed in dry form and others consist of mixtures of sweetened condensed milk and cocoa powder. Powders are likewise offered for sale containing dried egg and malted ingredients in addition to cocoa, sugar and dried milk. Bournvita and Ovaltine are proprietary articles of this kind. Their composition and calorific value are tabulated side by side with fresh milk and different grades of cocoa powder in Table XXVII,[16–21] where the calculation of the energy value is based on the conventional calorific values 9.3 per gram of fat and 4.1 per gram of protein. The value 4.1 calories per gram of carbohydrate has been adopted except for samples analysed by McCance and Widdowson, who used the factor 3.75 per gram of available carbohydrate (dextrose equivalent).

When white sugar is used for sweetening cocoa it contributes energy but no vitamins. On the other hand, raw sugar has a slightly lower energy value and contains several of the B vitamins, although thiamine is rarely present.[22]

According to Kon,[23] the average vitamin content per 100 grams of fresh milk is as follows: Vitamin A group and carotene 150 I. U., thiamine 45 μg., riboflavin 150 μg., nicotinic acid 80–400 μg., pantothenic acid 400 μg., pyridoxine hydrochloride 30 μg., biotin 5 μg.,

[15] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[16] S. K. Kon in *The Nation's Food* (edited by A. L. Bacharach and T. Rendle) Heffer, Cambridge, England, 1946.
[17] Anon., *Gordian Essays on Cocoa.* Rieck, Hamburg, 1936.
[18] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[19] R. A. McCance and E. M. Widdowson. *Chemical Composition of Foods.* His Majesty's Stationery Office, London, 1942.
[20] Unpublished data by the author.
[21] V. H. Mottram and G. Graham, *Hutchinson's Food and the Principles of Dietetics.* Arnold, London, 1940.
[22] R. Cowgill and W. A. Krehl, *Finding to Problem No. 27, Work in Progress, Sugar Research Foundation,* 4, 1947; *Internat. Sugar J., 50,* 55 (1948).
[23] S. K. Kon in *The Nation's Food* (edited by A. C. Bacharach and T. Rendle). Heffer, Cambridge, England, 1946.

inositol 14 mg., ascorbic acid 2 mg. and calciferol 21 I. U. Vitamin A potency of milk depends on the diet of the cow and is at its maximum when the animal is on grass. Thiamine content is independent of feed and riboflavin somewhat dependent on feed. According to Escudero and co-workers,[24] 4.5% of the thiamine, 21.6% of the riboflavin and no nicotinic acid are lost through boiling milk. Nevertheless, a cup of cocoa made up with freshly boiled milk has a higher nutritional value than a cocoa mixture containing dried milk, owing to a loss of up to 50% of the thiamine during roller drying. Since a 40% loss of thiamine is incurred in the manufacture of condensed milk,[25] fluid cocoa mixtures might be expected to have a slight advantage over powdered preparations, except those made with spray-dried milk.

Milk makes a valuable mineral contribution to a cup of cocoa, irrespective of the form in which it is introduced. Kon[26] states that 100 g. of milk contain calcium 0.12 g., magnesium 0.10 g., phosphorus 0.10 g. and iron 0.03 mg.

2. Bittersweet and Sweet Chocolate Tablets

The general composition and approximate calorific values of eight British-made chocolates are shown in Table XXVIII.[27] These chocolates were analysed by the author who determined their moisture content by oven-drying to constant weight, fat by continuous extraction with petroleum ether and sucrose polarimetrically. With the exception of the seventh sample, they fulfil the U. S. A. requirements for bittersweet chocolate, because their chocolate liquor content (non-fat cacao solids times 2.2) exceeds 35%.

In Table XXIX,[28] calorific values are shown for chocolates prepared from three different recipes. The fat contents are identical in the

[24] A. Escudero, M. L. Herraiz and H. G. de A. Herrero, *Rev. asoc. Argentina dietol., 1*, 119 (1943); *Chem. Abstracts, 39*, 2822 (1945).

[25] R. S. Harris and B. E. Proctor, *Proceedings First Food Conference, Institute of Food Technology, 1*, 109 (1940).

[26] S. K. Kon in *The Nation's Food* (edited by A. L. Bacharach and T. Rendle). Heffer, Cambridge, England, 1946.

[27] Composition of British-made plain chocolate bars and couvertures. Unpublished data by the author, British Food Manufacturing Industries Research Association.

[28] Composition and calorific value of chocolate. H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.

TABLE XXVIII. Composition of British-made Plain Chocolate Bars (Sweet Chocolate) and Couvertures (Sweet Chocolate Coating)[a]

Moisture, %	1.50	0.77	0.87	0.90	0.80	2.22	0.77	0.99
Fat, %	37.22	36.32	34.02	40.23	40.67	33.84	36.92	38.30
Sucrose, %	41.60	44.05	44.11	41.37	37.34	39.77	49.66	43.81
Non-fat cacao solids (by difference), %	19.68	18.86	21.00	17.50	21.19	24.17	12.65	16.90
Calories per 100 g	580	580	560	600	605	570	590	595

[a] Unpublished data by the author. British Food Manufacturing Industries Research Association.

TABLE XXIX. Composition and Calorific Value of Chocolate[a]

	40% Cacao mass 10% Cocoa butter 50% Sugar	51% Cacao mass 4% Cocoa butter 45% Sugar	44% Cacao mass 16% Cocoa butter 40% Sugar
Moisture, %	1	1	1
Fat, %	32	32	40
Protein, %	4	5.5	5
Theobromine, %	0.6	0.7	0.7
Carbohydrates, tannins, etc., %	60	58	51
Crude fibre, %	1.1	1.4	1.2
Ash, %	1.1	1.4	1.2
Calories per 100 g	560	560	600

[a] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.

first and second recipes cited and the energy derived from the excess of sugar in the first one appears to be counterbalanced by the excess of non-fat cacao solids in the second one. The influence of the higher fat content in the third recipe is demonstrated by its enhanced energy value.

The average composition of five samples of chocolate analysed by McCance and Widdowson[29] is given below.

Moisture trace, protein 4.6%, fat 32.5%, sugar (converted to invert sugar) 52.6%, starch and dextrins (expressed as dextrose equivalent) 6.1%, available carbohydrate 58.7%, calories per 100 grams 541.

With a calorific value of 540 to 600 per 100 grams, chocolate is superior to other kinds of sugar confectionery as an energy-producing food and derives its advantage from a relatively high fat content. The

[29] R. A. McCance and E. M. Widdowson, *Chemical Composition of Foods*. His Majesty's Stationery Office, London, 1942.

energy value of boiled sweets (97% sugars) is 398 calories per 100 grams. Toffee containing 15% of fat and 6% of moisture will provide about 460 calories per 100 grams.

According to Fincke,[30] the mineral content of a chocolate containing 40% of cacao mass (chocolate liquor) is 1.24% and the mineral constituents, in milligrams per 100 grams of chocolate, are K_2O 420, Na_2O 16, CaO 50, MgO 200, Fe_2O_3 4, Al_2O_3 4, P_2O_5 420, SO_3 38, Cl 12 and SiO_2 4.

McCance and Widdowson[31] give the following values for elements in milligrams per 100 grams of chocolate:

K 397, Na 18.6, Ca 26.1, Mg 81.7, Fe 3.28, Cu 1.11, P 139, S 32, Cl 8.8. Acid-base balance 79.0 ml. 0.1*N* alkali per 100 grams.

TABLE XXX. Composition of British-made Milk Chocolate Bars and Couverture (Coating)[a]

Moisture, %	1.37	1.45	0.84	1.00	0.92	1.00	1.54	1.62
Fat, %	32.57	40.43	34.77	36.90	37.21	32.82	37.83	32.35
Lactose, %	9.50	8.50	8.68	7.92	7.60	7.15	10.31	11.92
Milk protein, %	7.04	6.53	7.04	5.88	5.63	5.07	7.64	8.83
Milk ash (estimated), %	1.50	1.37	1.43	1.25	1.20	1.11	1.63	1.88
Sucrose, %	38.40	36.34	41.50	42.24	42.06	48.16	35.45	37.67
Non-fat cacao solids (by difference), %	9.62	5.38	5.74	4.81	5.38	4.69	5.60	5.73

[a] From unpublished data by the author. British Food Manufacturing Industries Research Association.

Escudero and co-workers[32] determined the average vitamin content of 22 South American chocolates and found carotene 0.057 mg., nicotinic acid 9.5 mg., thiamine 144 μg. and riboflavin 134.5 μg. per 100 grams.

The following vitamin contents per ounce[33] were found in chocolate of British make: Vitamin A, 7 I.U.; thiamine, 0.03 mg.; nicotinic acid, 0.3 mg.; ascorbic acid and calciferol, nil. By bioassay, Knapp and

[30] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[31] R. A. McCance and E. M. Widdowson, *Chemical Composition of Foods*. His Majesty's Stationery Office, London, 1942.
[32] A. Escudero, R. A. Senra, H. G. de A. Herrero, A. F. Castallanos, J. F. B. Garcia Crespo, A. M. Benedetto, M. A. Laserate and J. Lavarello, *Rev. asoc Argentina dietol.*, 5, No. 17, 61 (1947); *Chem. Abstracts*, *42*, 2692 (1948).
[33] Anon., *Manual of Nutrition* (Appendix). Ministry of Food. His Majesty's Stationery Office, London, 1945.

Coward[34] found 1 I.U. (0.025 μg.) of calciferol per gram of nib used in chocolate made from West African cacao.

3. Milk Chocolate

Variations in the proportions of milk and chocolate liquor ingredients used in the manufacture of British milk chocolates are illustrated by the analyses of eight samples listed in Table XXX.[35] The approximate content of fat-free milk solids (sum of lactose, protein and milk ash) ranges from 12 to 20% and the chocolate liquor present (percentage of non-fat cacao solids times 2.2) varies from 10 to 21%. In these samples, selected from a large number analysed prior to 1939 by the author, moisture and fat contents were determined by the methods described on p. 210, sucrose was determined polarimetrically

TABLE XXXI. Composition and Calorific Value of Milk Chocolate[a]

	A[b]	B[c]	C[d]	D[e]
Moisture, %	1	1	1	1
Fat, %	26	27	33	31
Protein, %	9.5	9.5	9	10.5
Theobromine, %	0.15	0.15	0.2	0.4
Carbohydrates, tannins, etc., %	60	59	53	53
Crude fibre, %	0.3	0.3	0.4	0.7
Ash, %	2.2	2.1	2.1	2.5
Calories per 100 g.	525	530	565	550

[a] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[b] A composition: 10% cacao mass, 20% cocoa butter, 46% sugar, 4% whole milk solids, 20% skim milk solids.
[c] B composition: 10% cacao mass, 18% cocoa butter, 45% sugar, 15% whole milk solids, 12% skim milk solids.
[d] C composition: 13% cacao mass, 20% cocoa butter, 39% sugar, 23% whole milk solids, 5% skim milk solids.
[e] D composition: 27% cacao mass, 9% cocoa butter, 34% sugar, 30% whole milk solids.

by the difference between the angular rotation before and after inversion, lactose was calculated from the copper-reducing power of clarified solutions and casein was isolated by precipitation from sodium oxalate extracts of the chocolate. Milk protein was calculated as casein times 1.1. The mineral matter due to milk solids was estimated by pro-

[34] A. W. Knapp and K. H. Coward, *Analyst, 59,* 474 (1934).
[35] Composition of milk chocolate bars and couverture. Unpublished data by the author. British Food Manufacturing Industries Research Association.

portion from lactose and milk protein contents. Non-fat cacao solids were calculated by difference.

The composition and estimated calorific values of milk chocolates prepared from different recipes are given in Table XXXI.[36]

McCance and Widdowson[37] give the following average composition for five samples of milk chocolate:

Moisture 1.3%, fat 34.1%, protein 7.4%, available carbohydrate (monosaccharide equivalent) 52.3%, calories per 100 grams 543.

From the examples cited above it will be seen that the energy value of milk chocolate is only slightly lower than that of sweet chocolate. Nutritionally, milk chocolate is superior to ordinary chocolate in respect of the high biological value of milk protein. Notwithstanding the deterioration of about 5% of the protein as a consequence of spray-drying and rather more during roller-drying, the biological value of the dried milk protein is considerably higher than that of cacao protein.[38]

Valuable contributions of calcium and phosphorus are made by milk. According to Fincke,[39] milk chocolate containing 20% of cacao mass and 20% of milk solids yields an ash of 1.82% and contains K_2O 498, Na_2O 80, CaO 313, MgO 130, Fe_2O_3 6, Al_2O_3 2, P_2O_5 534, SO_3 49, Cl 168 and SiO_2 1 mg. per 100 grams of chocolate.

Average values for the mineral constituents of five samples of milk chocolate analysed by McCance and Widdowson,[40] are K 487, Na 93.4, Ca 175, Mg 57.4, Fe 1.7, Cu 0.14, P 215, S 67, and Cl 132 mg. per 100 grams.

McCance and Widdowson state that 18% of the phosphorus is in the form of phytic acid and therefore not available.

The vitamin content of chocolate is increased through the presence of full-cream milk solids. A fairly high proportion of the vitamins in milk survive processing. Kon[41] states that 10% of the thiamine and

[36] Composition and calorific value of milk chocolate. H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[37] R. A. McCance and E. M. Widdowson, *Chemical Composition of Foods*. His Majesty's Stationery Office, London, 1942.
[38] S. K. Kon in *The Nation's Food* (edited by A. L. Bacharach and T. Rendle). Heffer, Cambridge, England, 1946.
[39] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[40] R. A. McCane and E. M. Widdowson, *Chemical Composition of Foods*. His Majesty's, Stationery Office, London, 1942.
[41] S. K. Kon in *The Nation's Food* (edited by A. L. Bacharach and T. Rendle). Heffer, Cambridge, England, 1946.

20% of the ascorbic acid are lost during the manufacture of spray-dried milk. When copper pans are used, almost the whole of the ascorbic acid is lost. Vitamin losses may be as high as 30% during the manufacture of roller-dried milk. The fat soluble vitamins in skim milk are negligible.

Steudel[42] found a high content of vitamin A in Swiss milk chocolate prepared from condensed milk and detected vitamin A and thiamine in full cream powdered milk chocolate.

The following amounts of vitamins per ounce[43] have been reported in British chocolate: Vitamin A, 30 I.U. (6.6 μg.); thiamine, 0.01 mg.; riboflavin, 0.07 mg.; nicotinic acid, nil, ascorbic acid, 0.3 mg.; and calciferol, 0.3 mg.

4. Cacao Shell as Cattle Food

The composition of cacao shell is given in Chapter VII, Table XVIII. Although the protein content (13.5–14.1%) is high, only 44% to 50% of the whole is digestible.[44] Kellner[45] estimated that the nutritional value of shell is 45% of that of starch meal. Pfeiffer and Clarenz[46] state that 100 kg. of cacao shell have a biological value corresponding to 42 kg. of wheat bran.

The following joint announcement was made by the Ministry of Food and the Ministry of Agriculture in Great Britain:[47]

"Cocoa and chocolate residues including shell are suitable for feeding to adult cattle provided that the daily ration does not exceed more than 2 lb. of this material.

"In the case of pigs, poultry and calves they are detrimental and the cumulative effect may be serious. Cocoa residues are sold for inclusion in cattle foods to the extent of 2.5% for feeding to adult cattle only."

See Chapter VII, 13A(2) for calciferol content of sun-dried shell and enrichment of milk through use of shell as fodder.

[42] H. Steudel, *Die Ernährung, 5,* 229 (1940); *Internat. Choc. Rev., 2,* 342 (1947).
[43] *Manual of Nutrition* (appendix), Ministry of Food. His Majesty's Stationery Office, London, 1945.
[44] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[45] O. Kellner, *Die Ernährung der landwirtschaftlichen Nutztiere,* 216, 616 (1916); H. Fincke, *Handbuch der Kakaoerzeugnisse,* Springer, Berlin, 1936.
[46] G. Pfeiffer and L. Clarenz, *Biochem. Zeitschr., 285,* 195 (1936).
[47] *Analyst, 68,* 216 (1943).

CHAPTER XI

METHODS OF ANALYSIS

1. Substitutes and Additions

Several cocoa and chocolate substitutes have been patented. They include peas roasted under vacuum,[1] lentils roasted to a dark brown colour,[2] chestnuts and beechnuts and deproteinised chestnut starch flavoured with vanilla, cinnamon or sandalwood and 1% of salt, and coloured with caramel.[3] Kola paste was used as an ingredient of German chocolate in wartime and soya flour replaced milk solids in prepared cocoa powders.[4] In countries where sugar is in short supply, artificial sweeteners are used to replace part of the sugar.

The use of a relatively large quantity of alkali primarily for the sake of darkening cocoa is a fairly uncommon practice nowadays. Sometimes colouring matter is added to so-called cacao products with the intention of deceiving the consumer. Some years ago, the author's attention was drawn to a "chocolate" sponge cake offered for sale, which contained a synthetic dyestuff and vanilla flavouring but was entirely devoid of cacao solids. The addition of carbon black for the purpose of darkening chocolate has been reported in the United States.[5]

Small quantities of starch or gums are sometimes added to cocoa powders to delay sedimentation. A mixture of chocolate liquor, sugar and foreign starch is marketed in Europe as "drinking chocolate."

In countries where cocoa butter is in short supply, no particular restrictions are placed in the use of substitute fats. In the United States, vegetable fats other than cocoa butter may be used only in

[1] Belgian Pat. 430,375 (Aug. 22, 1939), H. Pappenheim.
[2] Swiss Pat. 223,294 (Nov. 16, 1942), O. Joko.
[3] French Pat. 880,616 (Mar. 31, 1943), S. A. Unipectine.
[4] R. W. Pilcher, W. B. Esselen and C. J. Mangan, *British Intelligence Objectives Sub-committee Miscellaneous Report No. 38.* His Majesty's Stationery Office, London, 1945.
[5] A. P. Sidaras, *J.A.O.A.C., 32,* 145 (1949).

types of chocolate coatings retailed in warm climates or for covering frozen foodstuffs. Oils of the coconut class are easily detected by analysis. The presence of fats such as Borneo tallow and Chinese vegetable tallow is more difficult to establish because their chemical and physical characteristics are somewhat similar to those of cocoa butter. Commercial "illipe" butters sometimes consist of mixtures of Borneo and Chinese vegetable tallows.

The aroma of butter is attributed to the presence of diacetyl. Synthetic diacetyl is sometimes used as a flavouring ingredient for confectionery. Schmallfuss and Barthemayer[6] detected 0.12% of diacetyl in a sample of Dutch cocoa. Ingredients imitating butter flavour may not be used for cacao products in the United States.

The presence of excessive quantities of cacao shell in cocoa or chocolate is comparatively uncommon nowadays and is more likely to arise through inefficient processing than by deliberate addition. Owing to the scarcity of coffee during World War II, a process was patented in Switzerland for working up cacao shell and waste as a *coffee* substitute.[7]

It is sometimes necessary for the analyst to investigate claims made with respect to improvements in the dietetic value of chocolate commodities, for example vitamin additions, tannin removal or the suitability of special products for diabetics.

The microscope is an indispensable aid for the detection of added cereals, nuts, soyaflour, kola paste and contaminants such as moulds and cacao shell. To facilitate the recognition of shell, Plahl[8] recommends staining by treatment with ferric chloride, potassium cyanide and Congo red. The mucilage cells of the shell then stand out clearly in blue. Other tissues are coloured red or greenish brown. Nicholls[9] describes the salient features of cacao shell as a parenchyma of large mucilage cells, a layer of small, thick-walled stone cells and the presence of a greater number of spiral vessels than is found in the nib. Multicellular hairs of the perisperm (also called Mitscherlich bodies) may occur in either nib or shell. Fragments of shell are stained pink by a solution containing 0.02% of ruthenium red and 10% of lead acetate.

[6] H. Schmallfuss and H. Barthemayer, *Z. Untersuch. Lebensm., 63,* 283 (1932).
[7] Swiss Pat. 221,304 (August 17, 1942), Chocolat Tobler A.-C.
[8] W. Plahl, *Z. Untersuch. Lebensm., 70,* 289 (1935).
[9] J. R. Nicholls, *Aids to Analysis of Foods and Drugs.* 7th ed., Ballière, Tindall and Cox, London, 1952.

2. Analysis of Cacao Products

A. MOISTURE

The moisture content of cocoa or chocolate is determined by drying the sample to constant weight in a well-ventilated oven. The slight loss incurred by volatilisation of flavouring matter is negligible. When the oven temperature does not exceed 100°C., it is unlikely that any changes of a chemical nature are involved and it is therefore unnecessary to resort to vacuum drying.

Methods of moisture determination were recently under discussion by a sub-committee of the Office International du Cacao et du Chocolat[10] and the following procedure was recommended.

Five grams of the sample, evenly distributed over 20 grams of previously washed and ignited sand in a nickel, aluminum or Petri dish, are oven-dried at 100°C. for four hours and for subsequent periods of 30 minutes until consecutive weighings show a difference of less than 0.1%. The dish and contents are cooled in a desiccator before each weighing.

The committee recommended that further study should be devoted to moisture determination by the Karl Fischer and toluene distillation methods.

TABLE XXXII. PERCENTAGE OF MOISTURE IN COCOA POWDER AND CHOCOLATE

Source	Cocoa powder	Sweet chocolate and milk chocolate
United States	5.25–7.8[a]	1.82–2.71[a]
Holland	5.95[a]	
Great Britain	2.75–6.35[b]	
	2.9 –5.0[c]	0.8 –2.0[c]
France	—	0.98–1.28[c]
Spain	—	1.2 –1.5[c]
Germany	5.4 –6.5[d]	1.0[d]

[a] A. L. Winton and K. B. Winton, *The Structure and Composition of Foods*. Vol. IV, Wiley, New York, 1939.
[b] H. E. Cox, *Chemical Analysis of Foods*. 4th ed., Churchill, London, 1950.
[c] R. Whymper, *Cocoa and Chocolate, Their Chemistry and Manufacture*. 2nd ed., Churchill, London, 1921.
[d] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.

[10] *Official Report, Congrès International des Fabricants de Chocolat et de Cacao, Lausanne, 1950*. Office International du Cacao et du Chocolat, Brussels, 1950.

Hinton and Taylor[11] have described a toluene distillation method for the determination of moisture in cacao products.

The spread of values for the moisture content of cocoa and chocolate from various sources is given in Table XXXII.[12–15]

B. ASH

The procedure recommended at the 1950 Conference of the Office International du Cacao et du Chocolat is summarised below.[16]

A platinum dish is covered with a watchglass and weighed. About five grams of cocoa or chocolate are introduced and accurately weighed. The watchglass is removed and the sample is incinerated at 550°C. until a white or greyish ash is obtained. The dish is covered with the watchglass, cooled in a desiccator and weighed.

Should the ash contain obstinate lumps of carbon, it is leached with water and filtered through an ashless paper into a beaker. The insoluble matter retained on the paper is dried in the oven and incinerated at 800°C. The filtrate is added to the cooled residue and evaporated to dryness on a water bath. The contents are then incinerated at 550°C. and the cooled dish, ash and watchglass are weighed.

(1) ADDED ALKALI

The presence of added alkali may be presumed when the ash content is abnormally high in relation to the cacao solids present. The proportions of soluble and insoluble ash will indicate whether soluble or insoluble alkali has been added.

Alkalinity of the water-soluble ash is determined by adding a measured quantity of standard acid to the solution and titrating the excess of acid remaining after the solution is boiled and cooled. Water-insoluble alkalinity is determined in a similar manner after solution in standard acid. Nicholls[17] states that the methyl orange end point is difficult to determine when the insoluble ash is titrated, because the indicator shows a tendency to be absorbed by the mineral matter.

[11] C. L. Hinton and A. McM. Taylor, *Bull. Officiel de l'Office Internat. du Cacao et du Chocolat, 9*, 189 (1939).
[12] A. L. Winton and K. B. Winton, *The Structure and Composition of Foods*, Vol. IV. Wiley, New York, 1939.
[13] H. E. Cox, *Chemical Analysis of Foods*. 4th ed., Churchill, London, 1950.
[14] R. Whymper, *Cocoa and Chocolate, Their Chemistry and Manufacture*. 2nd ed., Churchill, London, 1921.
[15] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[16] *Official Report, Congrès International des Fabricants de Chocolat et de Cacao, Lausanne, 1950*. Office International du Cacao et du Chocolat, Brussels, 1950.
[17] J. R. Nicholls, *Aids to Analysis of Foods and Drugs*. 7th ed., Ballière, Tindall and Cox, London, 1952.

Added alkali is estimated by deducting the average titration value for the alkalinity of the ash of an equivalent amount of cacao nibs from the observed titration for the alkalinity of the ash of the sample. The difference in volume is usually calculated to the equivalent of potassium carbonate and the percentage may be expressed in terms of the original nibs used.

Alkalisation with ammonia is not evident from the ash. For its determination, Jensen[18] recommends distillation of the sample with milk of lime or magnesia to liberate the ammonia.

The effects of alkalisation on the mineral content of cocoa powder are demonstrated in Table XXV, Chapter VIII.

Maximum and minimum values for the mineral content of cacao products (alkalised and unalkalised) are set out in Table XXXIII.[19–22] The natural mineral content is dependent on the percentage of fat-free cacao solids in the product, except in the case of milk chocolates, where the milk solids also contribute to the ash. Dutch and Belgian cocoa powders may be heavily alkalised.

C. CRUDE FIBRE AND CACAO SHELL

The crude fibre content of cocoa powder may be determined by gently boiling the fat-free dry matter for 30 minutes with 1.25% sulphuric acid and then boiling the washed residue for 30 minutes with 1.25% sodium hydroxide. The residue is freed from alkali by washing with hot water, then washed with alcohol and ether and dried to constant weight. It is then incinerated and the weight of mineral matter is deducted. The method is empirical and no deviations should be made from the procedure used to obtain basic data for the fibre content of different types of nibs and shell. In cacao products which contain sugars or milk, the percentage of fat-free cacao solids must be determined by analysis or they can be estimated by the A.O.A.C.[23] method which is designed to eliminate interference due to non-cacao ingredients.

Knapp and McLellan[24] studied the effect of particle size and found that the degree of grinding gave rise to variations in results.

[18] H. R. Jensen, *The Chemistry, Flavouring and Manufacture of Chocolate Confectionery and Cocoa.* Churchill, London, 1931.
[19] A. L. Winton and K. B. Winton, *The Structure and Composition of Foods.* Vol. IV, Wiley, New York, 1939.
[20] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[21] R. Whymper, *Cocoa and Chocolate, Their Chemistry and Manufacture.* 2nd ed., Churchill, London, 1921.
[22] H. E. Cox, *Chemical Analysis of Foods.* 4th ed., Churchill, London, 1950.
[23] *Methods of Analysis of the A.O.A.C.* 7th ed., Washington, D. C., 1950.
[24] A. W. Knapp and B. G. McLellan, *Analyst, 44,* 2 (1919).

TABLE XXXIII. MINERAL CONTENT OF CACAO NIBS AND COMMERCIAL PRODUCTS

		Nibs	Chocolate liquor	Cocoa powder			Sweet chocolate	Milk chocolate
				Unalkalised	Alkalised	Not stated		
U. S. A.[a]	Total ash, %	2.61–4.15	2.90–3.68		7.98[e]	3.84–8.48	0.96–2.00	
U. S. A.[a]	Soluble ash, %	0.73–1.86	1.24–1.74		6.46[e]	1.76–4.62	0.55–0.99	
Germany[b]	Total ash, %	2.78–3.47	3.06	5.26–5.69	6.7 –8.9		1.24–1.85	1.83–2.26
Germany[c]	Total ash, %				5.18–5.43[f]			
Great Britain[c]	Total ash, %	2.52–3.81		4.4 –5	7.9 –8.6		1.1 –2.0	1.27–2.32[g]
Great Britain[d]	Total ash, %	4.02–4.15				5.6 –9.2	1.38–2.54	1.77–1.96
Great Britain[d]	Soluble ash, %	1.95–2.32				2.8 –5.7		

[a] A. L. Winton and K. B. Winton, *The Structure and Composition of Foods*. Vol. IV, Wiley, New York, 1939.
[b] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[c] R. Whymper, *Cocoa and Chocolate, Their Chemistry and Manufacture*. 2nd ed., Churchill, London, 1921.
[d] H. E. Cox, *Chemical Analysis of Foods*. 4th ed., Churchill, London, 1950.
[e] Dutch process.
[f] Alkalised with ammonia.
[g] Swiss origin.

TABLE XXXIV. CRUDE FIBRE IN FAT-FREE ROASTED CACAO NIBS AND SHELL[a]

	Per cent in nib	Per cent in shell
Accra	5.6	19.5
Kumasi	5.6	18.4
Nigeria	5.6	19.5
Arriba	6.3	15.5
Grenada	6.5	16.5
Bahia	5.5	17.8
Samoa	5.7	18.5
Trinidad	5.8	17.9
Jamaica	6.2	19.5
Ceylon	6.6	19.3

[a] H. C. Lockwood, *Analyst, 64,* 92 (1939).

Penetration by acid and alkali was less efficient when large particles were present. They refer also to the difficulty of defatting coarser material. Lockwood[25] states that uniformity of results can only be achieved by grinding the defatted material until the whole of it will pass through a screen with 100 meshes per inch. By reducing samples to this fineness, Lockwood found an average fibre content of 5.8% in fat-free dry cacao nibs and 18.5% in fat-free dry cacao shell from ten varieties of roasted beans (see Table XXXIV). Applying these results as being typical for cacao ground by modern machines, the percentage of shell, S, on a fat-free dry basis can be calculated from the equation

$$S = \frac{100}{12.7} \times (\text{fat-free dry fibre } \% - 5.8)$$

By making an allowance for the distribution of fat and moisture between nib and shell, the percentage of roasted shell in the original mixture is more accurately represented by the formula

$$\frac{100S}{(100 - S)\ \dfrac{(100 - b)}{(100 - a)} + S}$$

where S = dry fat-free shell in the dry fat-free mixture
a = fat + moisture in roasted nib
b = fat + moisture in roasted shell

[25] H. C. Lockwood, *Analyst, 64,* 92 (1939).

Using 58 and 8 as typical values for a and b respectively, Lockwood represents the above formula as

$$\frac{84S}{184 - S}$$

which can be expressed in terms of fibre (F) on the dry fat-free material as shown in the equation below

$$\text{Roasted shell in original mixture} = \frac{8400(F - 5.8)}{2337 - 100(F - 5.8)}$$

Fincke and Thaler[26] determined the crude fibre content of a range of cacao products by digestion with a solvent prepared by dissolving 25 grams of trichloroacetic acid and 62 ml. of concentrated nitric acid (sp. gr. 1.4) in 70% acetic acid (sp. gr. 1.069 at 20°C.) and making up to 1 litre with 70% acetic acid.

The amount of reagent used is adjusted according to the kind of sample under test. No previous defatting is necessary for cacao shell. All other materials are weighed into centrifuge tubes, defatted with petroleum ether, washed with alcohol (95% by volume), extracted twice with 70% acetic acid to remove the sugars and transferred to the digestion flask with the reagent. In the case of milk chocolate, the sample is digested with hot 70% acetic acid to dissolve milk protein as well as sugar. Appropriate sample weights and amounts of reagent are as follows:

Cacao shell 1 gram, 25 ml. of reagent
Cacao mass 3–4 grams, 50 ml. of reagent
Cocoa powder 2–3 grams, 50 ml. of reagent
Sweet chocolate 5–8 grams, 30–60 ml. of reagent
Milk chocolate 8–15 grams, 30–60 ml. of reagent

The pre-treated material is heated with the reagent for 30 minutes in an acetylation flask with air condenser, allowed to cool to 50–60°C., filtered through a tared sintered glass crucible containing an ashless filter pad and washed free of acid with hot water, followed by acetone and ether. The dried crucible is weighed. The filter pad and residue are then incinerated and the weight of ash deducted before calculating the percentage of fibre.

Fincke and Thaler found a mean fibre content of 5.44% in the fat-free dry nibs and 16.75% in the fat-free dry shell of cacao beans analysed by the above method. They also studied the effects of fine and coarse grinding and found that it was necessary to pass the samples through a 0.4- or 0.5-mm. sieve. As this is more easily done when the

[26] H. Fincke and H. Thaler, *Z. Untersuch. Lebensm., 84,* 97 (1942).

sample is dry, they found it convenient to determine the moisture content on the portion of sample weighed out for fibre determination.

Maximum and minimum values for the percentage of fibre in cacao products according to Winton[27] and Fincke[28] are given in Table XXXV. The maximum value for cocoa powder recorded by Winton indicates that a relatively high proportion of shell was present. The fibre contents of a number of cocoas retailed in Great Britain are noted in Chapter VIII, Table XXIV.

TABLE XXXV. PERCENTAGE OF CRUDE FIBRE IN CACAO PRODUCTS

	Chocolate liquor	Cocoa powder	Sweet chocolate	Milk chocolate
U. S. A.[a]	2.73–3.28	3.21–7.81	0.72–1.53	
Germany[b]	2.7	4.6 –5.0	1.1 –1.6	0.3–0.7

[a] A. L. Winton and K. B. Winton, *The Structure and Composition of Foods*. Vol. IV, Wiley, New York, 1939.
[b] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.

D. FAT AND FAT-SOLUBLE SUBSTANCES

(1) FAT DETERMINATION AND IDENTIFICATION

The following refractometric method for estimating the fat content of cacao products is due to Leithe and Heinz.[29]

Two grams of the sample are incorporated with 3 ml. of α-bromonaphthalene, with or without the aid of sand. The mixture is allowed to stand for two minutes and then filtered by suction. The refractometer reading of the solution is taken and the refractive index of the solvent is subtracted. The difference when multiplied by 10^4 is expressed as Δn. The fat content of the sample is obtained from Table XXXVI by reading the percentage corresponding to the observed value for Δn.

A rapid method of fat determination, suitable for control purposes mentioned by Nicholls[30] and more fully described by Kobe[31] depends on centrifuging two grams of cocoa or chocolate, or a larger quantity of material with low fat content, with petroleum ether. Three

[27] A. L. Winton and K. B. Winton, *The Structure and Composition of Foods*. Vol. IV, Wiley, New York, 1939.
[28] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[29] W. Leithe and H. J. Heinz, *Z. Untersuch. Lebensm., 72*, 414, 1936.
[30] J. R. Nicholls, *Aids to Analysis of Foods and Drugs*. 7th ed., Ballière, Tindall and Cox, London, 1952.
[31] E. X. Kobe, *Analytical Chem., 22*, 700 (1950).

or four extractions are necessary for complete removal of the fat. Kobe's results by this method are in close agreement with parallel tests by the A.O.A.C. method.

TABLE XXXVI. Fat Content from Change in Refractometer Reading, Using Bromonaphthalene as Solvent[a]

Δn	Fat, %	Δn	Fat, %
100	7.4	360	30.2
110	8.2	370	31.2
120	9.0	380	32.3
130	9.8	390	33.4
140	10.6	400	34.5
150	11.5	410	35.6
160	12.3	420	36.7
170	13.2	430	37.8
180	14.0	440	39.0
190	14.9	450	40.2
200	15.7	460	42.6
210	16.6	470	43.8
220	17.5	480	45.0
230	18.4	490	46.3
240	19.3	500	47.5
250	20.3	510	48.8
260	21.2	520	50.1
270	22.1	530	51.5
280	23.1	540	52.8
290	24.1	550	54.2
300	25.1	560	55.6
310	26.1	570	57.0
320	27.1	580	58.4
330	28.1	590	59.8
340	29.1	600	61.3

[a] W. Leithe and H. J. Heinz, Z. *Untersuch. Lebensm., 72,* 414 (1935).

The procedure used at the West African Cacao Research Institute[32] for the determination of fat, caffeine and theobromine in the same portion of raw cacao beans is summarised below.

Five grams of dried beans, with testas removed, are extracted with light petroleum for 20 hours in a Soxhlet apparatus. After evaporation of the solvent, the extract is dried to constant weight (A). The defatted residue is mixed with half its weight of magnesium oxide, wetted and partially dried and extracted

[32] *Annual Report, West African Cacao Research Institute,* p. 43, April 1948–March 1949. Crown Agents for the Colonies, London, 1950.

for 20 hours with chloroform. The dried extract (B) is allowed to stand overnight in 100 ml. of light petroleum before filtration through a tared Gooch crucible and the insoluble residue (C) is dried to constant weight. Caffeine is extracted from C by means of 100 ml. of benzene and the residue (D) collected on a second Gooch crucible.

$$A + B - C = \text{total fat}$$
$$C = \text{total alkaloids}$$
$$D = \text{theobromine}$$
$$C - D = \text{caffeine}$$

The results, expressed as percentage of fat in oven-dry nib, are given in Table XXXVII. Theobromine and caffeine contents were not published in the report.

TABLE XXXVII. PERCENTAGE OF FAT IN KERNELS OF RAW (DRIED) CACAO BEANS[a]

Stand no.	Progeny no.	Selection	Pet. ether extract (A) %	Chloroform extract (B−C) %	Total fat (A+B−C) %
794	T 92	Upper Amazon (crossed) = Nanay	56.84	0.92	57.76
910	T 82	Upper Amazon (crossed) = Nanay × Parinari	51.52	5.78	57.30
954	T 86	Upper Amazon (crossed) = Parinari	54.76	2.50	57.26
1298	T 48	Criollo (illegitimate) = Nicaraguan	54.58	2.58	57.26
1144	T 55	Upper Amazon (illegitimate) = Morona	52.52	4.60	57.12
823	T 63	Upper Amazon (crossed) = Nanay × Parinari	54.78	2.16	56.94

[a] *Annual Report. West African Cacao Research Institute*, p. 43. April 1948–March 1949. Crown Agents for the Colonies, London, 1950.

Continuous extraction methods are satisfactory for the majority of cacao products but give low results for the fat content of milk chocolate. Complete extraction is prevented by the envelope of casein surrounding the globules of milk fat. Acid treatment breaks down the barrier and releases the whole of the fat.

The following acid extraction method is recommended by the Office International du Cacao et du Chocolat.[33]

Three grams of cacao mass or five grams of cocoa or chocolate are weighed into a beaker and a few pieces of calcined pumice are added to regulate the boiling. 100 ml. of 4 *N* hydrochloric acid are added and the beaker is cov-

[33] *Official Report, Congrès International des Fabricants de Chocolat et de Cacao, Lausanne, 1950.* Office International du Cacao et du Chocolat, Brussels, 1950.

TABLE XXXVIII. CHEMICAL AND PHYSICAL CHARACTERISTICS OF COCOA BUTTER, CONFECTIONERY FATS AND OILS

		Zeiss butyro-refractometer reading, 40° C.	Refractive index at 40° C.	M. p., complete fusion, °C.	Solidifying point, ° C.	M. p. of fatty acids, °C.	Saponification value	Iodine value
Cocoa butter	Williams[a]	46.5–47.5	1.4570–1.4576	32–35	27–29.5	49–51	192–198	35–40
Extracted cocoa butter	Fincke[b]	47.2–48.6	1.4574–1.4584	32.8–44	—	50	190–193	38–49
Borneo tallow	Williams	45–47	1.4559–1.4573	28–36	28–32	54.6[e]	194	29–38
Chinese vegetable tallow	Williams	42–45	1.4538–1.4559	55–65	39–42	—	199–206	18–29
Butter fat	Hilditch[c]	42–45	1.4538–1.4559	28–33	19–24	38–45	228	26–45
Coconut oil	Williams	34.7–35.5	1.4486–1.4491	23–26	22–23.5	22–26	255–258	7.9–9.5
Coconut stearine	Williams	34.5–34.8	1.4485–1.4493	26–31	24–29	25–28.5[e]	252–255	2–8
Hardened coconut	Williams	—	—	27.5–31	24–25.6	—	252–255	3.2–6.5
Palm kernel oil	Williams	36–37.5	1.4495–1.4503	26–29	24–26.5	26–29	246–249	14.5–19
Palm kernel stearine	Williams	35.5–36	1.4491–1.4495	29–35	26.5–32	—	249–252	4–14.5
Soya oil	Elsdon[d]	62.5–63.5	1.4675–1.4686	—	−(5–13)	—	190–193	121–136
Walnut oil	Williams	64.5–67.5	1.4688–1.4707	—	—	—	193–197	138–148
Cashew nut oil	Elsdon	54.5	1.4623	—	—	—	193	79.5
Almond oil	Elsdon	56.5–57.5	1.4636–1.4643	—	−(10–20)	13–14	188–192	93–100

[a] K. A. Williams, *Oils, Fats and Fatty Foods*. 3rd ed., Churchill, London, 1950.
[b] H. Fincke, *Die Kakaobutter und ihre Verfälschungen*. Wissenschaftliche Verlagsgesellschaft, Stuttgart, 1929.
[c] T. P. Hilditch, *Industrial Fats and Waxes*. 2nd ed., Ballière, Tindall and Cox, London, 1947 (reprint).
[d] G. D. Elsdon, *Edible Oils and Fats*. Benn, London, 1926.
[e] A. W. Knapp, J. E. Moss and A. Melley, *Analyst, 52*, 453 (1927).

ered with a watchglass or condensing apparatus. The contents are brought slowly to the boil and the flame is withdrawn for a moment. Gentle boiling is then maintained for 15 minutes. The watchglass is rinsed with 100 ml. of boiling water trained into the beaker. The mixture is filtered very hot, through a wetted filter paper previously extracted with petroleum ether. The fat on the filter paper is washed with hot water until free from chloride. The paper and contents are placed in a previously defatted extraction thimble supported in a beaker and dried in an oven regulated to 102–103°C. and the fat in the dried material is subsequently extracted in a Soxhlet or similar apparatus. After thorough removal of solvent, the fat is dried in an oven to constant weight.

When it is necessary to identify the fat in a sample of chocolate or to determine whether a sample of cocoa butter is genuine, the chemical and physical characteristics of the fat are determined.

Standard procedures for determining the refractive index or the corresponding reading on the Zeiss butyrorefractometer scale, melting point, solidification point, melting point of fatty acids, iodine value of the fat and its fatty acids, saponification value, unsaponifiable matter, acid value, Reichert-Meissl, Polenske, and Kirschner values are described in the textbooks on fat analysis cited in Table XXXVIII and in *Methods of Analysis of the A.O.A.C.*

The presence of butter fat in a sample of chocolate can be identified by determining the Reichert-Meissl, Polenske and Kirschner values of the extracted fat. The Reichert-Meissl value is a measure of the proportion of water-soluble fatty acids present. Variations of the component of glycerides of butter fat occur between summer and winter. Hilditch[84] gives the following values for the acid components of butter fat. *Winter:* Butyric 3.7%, caproic 2.0%, caprylic 1.0%, lauric 1.7%, myristic 9.3%, palmitic 25.4%, stearic 10.7%, arachidic 0.4%, oleic 32.4%, other unsaturated acids 10.8%. *Summer:* Butyric 3.1%, caproic 1.7%, caprylic 0.7%, lauric 3.2%, myristic 7.1%, palmitic 22.8%, stearic 12.5%, arachidic 0.7%, oleic 41.3%, other unsaturated acids 5.1%.

The extreme range recorded for the Reichert-Meissl value of butter fat is 21 to 36. An average value of 28 may be used for the purpose of calculating the proportion of butter fat in milk chocolate after allowance has been made for the small proportion of volatile fatty acids due to cocoa butter.

Typical values for the chemical and physical characteristics of

[84] T. P. Hilditch, *Industrial Fats and Waxes*. 2nd ed., Ballière, Tindall and Cox, London, 1947 (reprint).

prime cocoa butter, solvent extracted cocoa butter, substitute fats marketed as illipe butter, butter fat, coconut oil, stearin and hardened fat, palm kernel oil and stearin and other vegetable oils which may be present in chocolate confectionery are shown in Table XXXVIII.[35–38]

(2) SUBSTITUTE FATS

Borneo tallow and Chinese vegetable tallow ("illipe" butters) are used as substitutes for cocoa butter. The former is not readily distinguished from cocoa butter by its chemical characteristics.

Tate and Pooley[39] devised a scheme for detection and approximate estimation of illipe fats, based on the product obtained by multiplying specific gravity at 60°C./15.5, specific gravity at 99°C./15.5, melting point, melting point of fatty acids, and viscosity at 60°C. by the reciprocal of the iodine value.

The product of all these factors lies between 3890 and 4771 (mean 4403) for illipe fat. The corresponding range for cocoa butter is from 2839 to 3347 (mean 3150). As might be expected, the observed values for mixtures were not strictly proportional and it is necessary to add a mean correction of 2.1, equal to half the maximum error to all results.

When the sample is small, the product of the melting point, melting point of fatty acids and reciprocal of the iodine value gives a "short" value, mean for illipe 56.15 and for cocoa butter 41.66.

Knapp, Moss and Melley[40] recommend the temperature at which the molten fatty acids solidify as the most promising means of distinguishing illipe butter from cocoa butter. The mean value for Borneo tallow is 54.6°C., whilst variations for cocoa butter are 49° to 50°C. Bywaters, Maggs and Pool[41] studied the cooling curves of the fats and noted the temperatures at which the first appearance of turbidity occurred. The mean values observed by this method were 30.8°C. for illipe fats and 21.4°C. for cocoa butter.

The presence of oils and stearines of coconut oil is indicated by a low refractive index and iodine value and a high saponification num-

[35] K. A. Williams, *Oils, Fats and Fatty Foods*. 3rd ed., Churchill, London, 1950.
[36] H. Fincke, *Die Kakaobutter und ihre Verfälschungen*. Wissenschaftliche Verlagsgesellschaft, Stuttgart, 1929.
[37] T. P. Hilditch, *Industrial Fats and Waxes*. 2nd ed., Ballière, Tindall and Cox, London, 1947 (reprint).
[38] G. D. Elsdon, *Edible Oils and Fats*. Benn, London, 1926.
[38a] A. W. Knapp, J. E. Moss and A. Melley, *Analyst, 52*, 453 (1927).
[39] F. G. H. Tate and G. W. Pooley, *Analyst, 46*, 229 (1921).
[40] A. W. Knapp, J. E. Moss and A. Melley, *Analyst, 52*, 453 (1927).
[41] H. W. Bywaters, F. T. Maggs and J. Pool, *Analyst, 52*, 325 (1927).

ber. An argentometric method for estimating coconut and oil has been published by the A.O.A.C.[42]

(3) DETECTION OF HARDENED FATS

The glyoxime test for nickel (used as a catalyst in hydrogenation) cannot now be regarded as satisfactory for establishing the presence of hardened fats because the amount of residual nickel in fats hardened by modern processes is so minute that it is barely detectable. Other methods for the detection of hardened fats depend on the presence of isooleic acid formed by hydrogenation of linoleic and linolenic acids. Bolton and Williams[43] described a method for estimating isooleic acid by fractionation of the lead salts of the fatty acids.

Under the German Customs Regulations 1937,[44] the following method was prescribed for the determination of isooleic acid.

One to 1.5 grams of the fat are saponified with 25 ml. of 2% alcoholic potassium hydroxide and then treated with 100 ml. of a solution prepared by dissolving 50 g. of normal lead acetate in 150 ml. of distilled water and 5 ml. of glacial acetic acid diluting to 1 litre with alcohol (95% by volume), 5 ml. of glacial acetic acid and 20 ml. of water. The lead salts of the solid fatty acids separate out on cooling. After standing overnight, they are filtered off on a sintered crucible, washed with 70% alcohol and dried. 5 ml. of acetic acid are added to the crucible and it is inverted over a flask containing 100 ml. of the lead reagent and boiled under reflux until all the lead salts are extracted. 15 ml. of hot water are added and the precipitated lead salts are redissolved by heating under reflux and allowed to crystallise at room temperature. They are filtered and washed with 50 ml. of 70% alcohol and re-extracted after adding 5 ml. of acetic acid to the filter and 95% alcohol to the flask. The alcoholic solution of lead salts is treated with 75 ml. of water and 100 ml. of nitric acid (sp. gr. 1.2) and extracted twice with 30-ml. portions of ether. The combined extracts are washed three times with 25 ml. of water and dried over anhydrous sodium sulphate. The ethereal extract is transferred to an iodine flask and after the bulk of the solvent has been evaporated, the residue is heated out of contact with air on a water bath until all traces of solvent and acetic acid are removed. 15 ml. of chloroform are added to the residue and its iodine absorption is determined by the Hanus method after standing for 20 minutes.

1 ml. of decinormal sodium thiosulphate solution is equivalent to 0.01412 g. of isooleic acid.

[42] *Methods of Analysis of the A.O.A.C.* 7th ed., Washington, D. C., 1950.
[43] E. R. Bolton and K. R. Williams, *Analyst, 55,* 5 (1930).
[44] J. R. Nicholls, *Aids to Analysis of Foods and Drugs.* 7th ed., Ballière, Tindall and Cox, London, 1952.

If S = weight of sample in grams, and
t = ml. of decinormal thiosulphate used (i.e., blank titration minus sample titration)

$$\text{isooleic acid } \% = \frac{100 \times 0.01412\ t}{S}$$

An allowance of 2.5% is made for naturally occurring isooleic acid.

(4) LINOLEIC ACID

The standard method of estimating linoleic acid is by means of the thiocyanogen value. The following simple oxidation method is due to Stainsby.[45]

One gram of fat is weighed into a 250-ml. round-bottom flask and dissolved in 100 ml. of acetone. Three portions of potassium permanganate, totalling 5 grams, are added at intervals of 5 minutes. The contents of the flask are then heated under reflux for 1 hour. The acetone is distilled off, removing the last traces by suction. The residue is dissolved in 50 ml. of normal sulphuric acid and hydrogen peroxide (20 volumes) is added gradually (about 25 ml.) until the brown colour is removed. The mixture is transferred to a separator and the fat is extracted first with 100 ml. of ether and again with 75 ml. The first ethereal extract is washed with 40 ml. of water which is used subsequently to wash the second extract. The two extracts are then united, washed with a further 40 ml. of water and transferred to a Polenske flask. After removal of ether, 210 ml. of recently boiled water are added and 200 ml. of liquid are distilled and collected. 100 ml. of water are added to the distillation flask and distilled until a total volume of 300 ml. is collected. The distillate is cooled, 75 ml. of ether-alcohol mixture, 2:1, is added and the acid glycerides are titrated with 0.1 N potassium hydroxide.

If O = oleoglyceride %
L = linoleoglyceride %
S = saturated acid %
I = iodine value of the fat
T = ml. 0.1 N potassium hydroxide used and
W = weight of fat taken, then

$$O + L + S = 100$$

$$\frac{56.1}{294.7} O + \frac{56.1}{292.7} L = \frac{56.1\ T}{10\ W}$$

$$\text{Linoleic acid} = \frac{100 \times I}{86.82} - \frac{2.927\ T}{W}$$

[45] W. J. Stainsby, *Analyst, 73,* 429 (1948).

(5) MINERAL OIL

A firm of chocolate makers was prosecuted at Ealing, England, in 1934 for preparing a chocolate coating containing paraffin wax. The case was dismissed for the technical reason that samples had been drawn in the factory and the defendants were therefore able to plead that the commodity had not been offered for sale. They undertook to destroy all stocks when the harmful nature of the wax was explained to them.

The presence of mineral oil or wax in the fat extracted from a sample of chocolate is indicated by the separation of an oily layer during the determination of the saponification value. When a relatively small quantity of mineral oil or wax is present, only a turbidity is produced. Confirmation of this form of adulteration may be obtained by the unusually low iodine value of the unsaponifiable matter. When an appreciable quantity of mineral oil is present, the iodine value of the original ether extract will also be remarkably low by comparison with that of cocoa butter.

(6) VITAMIN A

The method described below was published by Raynes and McLellan[46] for routine checks of vitamin A additions to cocoa and chocolate.

Five grams of sample are weighed into a 60-ml. beaker, 50 ml. of ether are added and any lumps are disintegrated. Two grams of filter aid are incorporated and the mixture is filtered through a sintered crucible containing an asbestos pad covered by a layer of filter aid, and washed twice with 10 ml. of ether. The pad is removed, re-extracted with 30 ml. of ether and filtered and washed as before. The solvent is removed and the residue is saponified with 15 ml. of freshly-prepared 0.5*N* potassium hydroxide. Fifteen ml. of water are added and the liquid is transferred to a separator, using 20 ml. of water for washing. 50 ml. of ether, used for rinsing, are transferred to the separator which is then well shaken. The ethereal layer is siphoned off and two further extractions are made. The united ethereal extracts are washed with small portions of water until neutral and filtered into a flask, and the filter is washed with ether. The solvent is evaporated and the last traces are removed under reduced pressure which is continued during cooling.

For chocolate containing 3000 I. U. of vitamin A, 20 ml. (precisely measured) of chloroform are added immediately to dissolve the unsaponifiable matter and 0.2 ml. of the solution is placed in a 1-cm. all-glass cell. 2 ml. of a solution

[46] E. C. Raynes and B. G. McLellan, *Analyst, 68,* 109 (1943).

of antimony trichloride (8.85% in chloroform) are added and the colour developed is matched against blue, yellow and neutral glasses in a Lovibond tintometer.

The factor 1.41 is used to convert Lovibond blue units to international units of vitamin A.

(7) VITAMIN D

The assay of vitamin D_2 (calciferol) in chocolate is measured biologically by determining its curative effect on rats suffering from rickets. A colorimetric method for the estimation of D vitamins is described by Palasi.[47]

When 1 to 2 mg. of calciferol, to which has been added 1 to 2 grams of sucrose, are dissolved in 1 to 2 ml. of ethyl alcohol and 2 drops of concentrated sulphuric acid are added, a red colour is produced. The addition of 6 drops of sulphuric acid gives a stark blue colour. When the test tube is shaken to mix the two layers, the colour diffuses to a pale limpid blue throughout. The intensity increases to a maximum within 15 minutes and is then stabilised as a sky blue colour, proportional in intensity to the concentration and thus obeying Beer's law. Ergosterol when similarly treated gives a clear violet colour.

(8) DIACETYL

Nicholls[48] states that about 0.04 mg. of diacetyl can be detected by the following procedure:

Forty grams of fat are steam-distilled and two fractions of 50 ml. are collected. Each fraction is placed in a small flask with 2.5 ml. of 20% sodium acetate, 0.1 ml. of 20% hydroxylamine hydrochloride and 0.1 ml. of 10% nickel chloride. The flask is connected with a small air condenser and maintained at about 50°C. for 30 to 60 minutes. If a pink colour develops, the liquid is transferred to an evaporating dish, evaporated to small bulk and the colour is matched against diacetyl standards similarly treated, by comparing the colour of the precipitates of nickel dimethylglyoxime retained on filter papers.

In a similar method, Dehove and Dessirier[49] recommend three extractions with chloroform to isolate the nickel dimethylglyoxime formed.

Den Herder[50] describes a distillation method with passage of carbon dioxide for 45 minutes at 65°C. The temperature is then

[47] V. V. Palasi, *Nature, 160,* 88 (1947).
[48] J. R. Nicholls, *Aids to Analysis of Foods and Drugs.* 7th ed., Baillière, Tindall and Cox, London, 1952.
[49] R. Dehove and L. Dessirier, *Ann. Falsif., 342,* 288 (1937).
[50] P. C. Den Herder, *Netherlands Milk and Dairy Journal, 1,* 110 (1947); *Analyst, 74,* 193 (1949).

raised to 100°C. and distillation is continued for 30 minutes. The distillate is collected in a solution of hydroxylamine.

(9) MONOGLYCERIDES

The following modification of Pohle, Mehlenbacher and Cook's[51] method for the determination of monoglycerides in fats and oils is due to Hantschumacher and Linteris.[52]

A quantity of fat sufficient to give a back titration exceeding 80% of the blank titration is weighed into a wide-mouthed bottle and dissolved in 15 ml. of a mixture of glacial acetic acid and chloroform, 2:1, and 25 ml. (accurately measured) of a solution of periodic acid (5 g. dissolved in 200 ml. of water and 800 ml. of glacial acetic acid) are added and mixed well. After standing for 10 minutes, the mixture is washed down from the sides of the flask with 5 ml. of glacial acetic acid. 15 ml. of potassium iodide and 100 ml. of water are added and the liberated iodine is titrated with a 0.1 N solution of sodium thiosulphate using starch as indicator.

If x = blank titration, y = sample titration, C = molecular weight of glyceride and W = weight of fat in grams,

$$\text{Monoglyceride} = \frac{100C\,(x - y)}{20{,}000W}$$

According to Pohle, Mehlenbacher and Cook, C = 281.8 for coconut and 354.4 for cottonseed, tallow, palm oil and soyabean monoglycerides.

(10) VANILLIN, ETHYLVANILLIN AND COUMARIN

Hoecke[53] devised the following tests to distinguish between vanillin and ethylvanillin (bourbonal):

When 4 N sodium hydroxide is added to vanillin, there is no colour development. When ethylvanillin is present, the mass becomes yellowish green. When vanillin is warmed with ferric chloride acidified with hydrochloric acid, slender needle-like crystals appear. Large cruciform groups of fine needles are formed when ethylvanillin is present. On warming vanillin with phenylhydrazine, oily droplets appear and set to a cream-coloured mass. They are not phototropic at room temperature. When ethylvanillin is treated similarly, small crystals are formed which exhibit reversible light phototropy. They appear red in the light and white on a dark background.

[51] W. D. Pohle, V. C. Mehlenbacher and J. H. Cook, *Oil and Soap, 22,* 115 (1945); *Analyst, 73,* 34 (1948).
[52] E. Hantschumacher and L. Linteris, *J. Amer. Oil Chemists Soc., 24,* 143 (1947); *Analyst, 73,* 34 (1948).
[53] F. Hoecke, *Chem. Weekbl., 35,* 316 (1938); *Analyst, 63,* 448 (1938).

A photometric method for the determination of vanillin in extracts, depending on the formation of an orange-brown colour with *ortho* iodoxyammonium benzoate in hydrochloric acid at pH 0.87, is described by Daniels, Emery and Prather.[54]

Freeland[55] has published a method for the determination of vanillin in cocoa butter and chocolate which involves extraction of a solution of the fat in petroleum ether with dilute ammonia, extraction of the acidified aqueous phase with ether and subsequent purification of the crude vanillin. The purified vanillin is then treated with *para*-toluidine and made alkaline. The excess of alkali can then be back-titrated with 0.05 *N* sulphuric acid.

1 ml. of 0.05 *N* alkali is equivalent to 0.0076 g. vanillin.

A mean recovery of 88% of the actual quantity of vanillin present is claimed.

Lockwood[56] has described a bromometric method for determination of ethylvanillin. Monobromo derivatives of vanillin and ethylvanillin can be distinguished by their melting points. Monobromovanillin melts at 162°C. and monobromoethylvanillin at 140°C.

By the following test, due to Kröller,[57] coumarin can be distinguished from vanillin and ethylvanillin.

Ten grams of a sample of cocoa or chocolate are shaken with 30 ml. of chloroform and filtered. 1 ml. of the filtrate is transferred to a test tube. 1 ml. of a 1% solution of indole in methyl alcohol is added and the solution is acidified with 1 ml. of 70% perchloric acid or 1 ml. of sulphuric acid. The same colour (cherry red) is developed in the presence of vanillin or ethylvanillin and it can be matched against standards prepared from 0.2 to 1 ml. of a solution of 0.1 g. of vanillin in 30 ml. of chloroform.

Coumarin treated similarly gives no colour and heliotropin only a faint yellow tint.

E. SUGARS

Standard methods for the determination of sugars are fully described by Browne and Zerban,[58] and methods for the analysis of

[54] T. C. Daniels, B. Emery and D. Prather, *J. Ind. and Eng. Chem. (Anal.), 10,* 320 (1938).
[55] D. M. Freeland, *Analyst, 57,* 9 (1932).
[56] H. C. Lockwood, *Analyst, 59,* 732 (1934).
[57] E. Kröller, *Deut. Lebensm. Rundschau, 46,* 6 (1950); *Chem. Abstracts, 44,* 3623 (1950).
[58] C. A. Browne and F. W. Zerban, *Physical and Chemical Methods of Sugar Analysis.* 3rd ed., Wiley, New York, 1941. Chapman and Hall, London, 1941.

sweetening materials in cacao products are published by the Association of Official Agricultural Chemists.[59] The following procedures for the determination of sucrose and lactose in chocolate have been recommended by the Office International du Cacao et du Chocolat.[60]

Ten grams of the finely grated chocolate are weighed into a 250-ml. Erlenmeyer flask, 0.5 g. of calcium carbonate and 100 ml. of water are added and the weight of the flask and contents is noted. The sugars are dissolved by warming to 50–60°C. After cooling, the flask is reweighed and the water lost by evaporation is replaced. 2 ml. of 40% lead subacetate solution are added and the mixture is well shaken and filtered (solution A).

To determine the percentage of sucrose in the chocolate, 50 ml. of solu-

TABLE XXXIX. Estimation of Lactose by Luff-Schoorl Method[a]

Sodium thiosulphate, ml. $N/10$	Anhydrous lactose, Mg.	Hydrated lactose, Mg.
1	3.6	3.8
2	7.3	7.7
3	11.0	11.6
4	14.7	15.5
5	18.4	19.4
6	22.1	23.3
7	25.8	27.2
8	29.5	31.1
9	33.2	35.0
10	37.0	39.0
11	40.8	43.0
12	44.6	47.0
13	48.4	51.0
14	52.2	55.0
15	56.0	59.0
16	59.9	63.1
17	63.8	67.2
18	67.7	71.3
19	71.7	75.5
20	75.7	79.7
21	79.8	84.0
22	83.9	88.3
23	88.0	92.6

[a] *Official Report, Congrès International des Fabricants de Chocolat et de Cacao, Lausanne Conference 1950.* Office International du Cacao et du Chocolat, Brussels, 1950.

[59] *Methods of Analysis of the A.O.A.C.* 7th ed., Washington, D.C., 1950.

[60] *Official Report, Congrès International des Fabricants de Chocolat et de Cacao, Lausanne, 1950.* Office International du Cacao et du Chocolat, Brussels, 1950.

tion A and 0.6 g. of freshly calcined calcium oxide are introduced into a 100-ml. volumetric flask and heated for one hour at 70°C. The contents are cooled to 20°C. and neutralised to phenolphthalein with dilute sulphuric acid and clarified with 2 ml. of lead subacetate and 1 ml. of saturated disodium phosphate. The contents of the flask are diluted to 100 ml., shaken, and filtered. The optical rotation of the filtrate is determined in a 200-mm. polarimeter tube, using sodium light. The reading is multiplied by the factor 0.986 to allow for the volume of calcium oxide and defecant.

Lactose is determined by pipetting 25 ml. of solution A into a 100-ml. volumetric flask. One milliliter of saturated disodium phosphate is added and the solution is made up to 100 ml. and filtered. Twenty milliliters of the filtrate, 25 ml. of Luff's reagent (prepared by dissolving 25 g. of crystalline copper sulphate in 100 ml. of water, 50 grams of crystalline citric acid in 50 ml. of water and 388 grams of crystalline sodium carbonate in 300–400 ml. of warm water and cooling. The citric acid solution is added to the sodium carbonate solution and the mixture is then added to the copper sulphate solution and diluted to 1 liter) and 5 ml. of water are measured into a 250-ml. Erlenmeyer flask, some fragments of pumice are added and the flask is connected to a reflux condenser. The contents are brought to the boiling point in two minutes and gently boiled for 10 minutes and quickly cooled. Three grams of potassium iodide (dissolved in a little water) are added and 25 ml. of 25% sulphuric acid are cautiously added. The liberated iodine is titrated with 0.1 N sodium thiosulphate and the titration is deducted from that of a reagent blank. The weight of lactose hydrate n corresponding to this difference in volume is read from Table XXXIX.

If S = percentage of sucrose in the chocolate, and d = angular rotation of the solution in a 200-mm. tube, then for chocolate containing no milk solids

$$S = \frac{15.124d}{1 - 0.09193d}$$

For milk chocolate, the percentage of sucrose is calculated by the following equation

$$S = \frac{15.124d}{1 - (0.09193d + 0.1178n)}$$

where n = the quantity of lactose hydrate (in grams) contained in the 20 ml. of solution used for the titration.

The percentage of lactose hydrate,

$$L = \frac{(204 + 0.124S)n}{1 - 0.1178n}$$

A close approximation may be obtained from the equation

$$L = (204 + 0.1245)n$$

Fat-free dry milk solids $= L \times 1.9$.

When discussing an earlier draft of the above method, Thaler[61] stated that more accurate results can be obtained by omitting the first lead precipitation, substituting barium hydroxide for calcium oxide and neutralising with 15% acetic acid in place of sulphuric acid. These variations necessitate the use of a separately weighed quantity of chocolate for the lactose determination.

Hinton and Macara[62] investigated polarimetric, chloramine titration and Fehling's solution titration methods for the determination of sucrose and lactose in chocolate. Lactose determination by the chloramine method is subject to an error of about 0.3% due to the effect of cacao solids. A smaller error was observed for Fehling's titration by the Lane and Eynon method.[63] For the analysis of sugars in milk chocolate, they recommend Lane and Eynon's method for lactose determination, polarimetric or chloramine methods for sucrose only and chloramine or Lane and Eynon methods for the determination of both sugars in the same sample.

F. SUGAR SUBSTITUTES

(1) SACCHARIN AND DULCIN

Saccharin and dulcin can be distinguished by their melting points and solubility in water. Saccharin melts with decomposition at 228°C. One gram will dissolve in 300 ml. of cold water or 25 ml. of hot water. Saccharin is readily soluble in alkali. It is 550 times sweeter than sugar. Dulcin melts at 173–174°C. One gram will dissolve in 800 ml. of cold water or 50 ml. of hot water. Dulcin is 200 times sweeter than sugar. Its presence in foodstuffs is harmful because it retards growth and can cause anaemia and liver tumours.[64]

Procedures for the detection and determination of saccharin are described in *Methods of Analysis* of the A.O.A.C.

A quantitative method for the determination of dulcin (recovery 80–90%) is described by Bass and Longwell.[65]

Ten milliliters of approx. 0.1% solution of dulcin are refluxed with 50 ml. of 3 *N* sulphuric acid for 3–4 hours, cooled, made alkaline with 40% sodium

[61] H. Thaler, *Z. Untersuch. Lebensm., 80,* 439 (1940).
[62] C. L. Hinton and T. Macara, in *Official Report, Congrès International des Fabricants du Chocolat et Cacao,* 341 (1930).
[63] J. H. Lane and L. Eynon, *J. Soc. Chem. Ind.,* 32T (1923).
[64] *Ann. Rept. Federal Security Agency,* 1950 p. 20.
[65] J. Longwell and C. S. Bass, *Analyst, 67,* 14 (1942).

hydroxide and steam-distilled into 15 ml. of 0.1 *N* hydrochloric acid. Separate lots of 500 ml., 100 ml. and 100 ml. of distillate are collected and tested by introducing 15–20 ml. into Nessler tubes and comparing the colour of the solutions with a series of standards prepared from 2.5–4.5 ml. of a 0.01% solution of *p*-phenetidine diluted with water. To each tube, 4 ml. of 0.1 *N* hydrochloric acid are added, the tubes are cooled below 10°C., 1 ml. of 1% sodium nitrite is then added and, after 10 minutes, 0.5 ml. of 1% phenol solution is added.

When the solutions are made alkaline with 3 ml. of an 8% solution of sodium hydroxide, the reddish yellow colour developed is matched against the standards. Differences of 0.2 ml. between standards can be detected.

The factor 1.037 is used to convert phenetidine to dulcin.

(2) *d*-SORBITOL

d-Sorbitol is a hexahydric alcohol with a pleasantly sweet taste. It is used as an ingredient of diabetic chocolate.

Valencin and Deshues[66] found 13% of *d*-sorbitol in a diabetic chocolate of Swiss make analysed by the following method:

Two grams of chocolate are broken down with 50 ml. of 95–98% ethyl alcohol and centrifuged. The operation is repeated and the solvent evaporated. The residue is taken up in warm water and filtered to remove the fat. Most of the water is evaporated and to the residue, containing 0.25 ml. of water, 0.8 ml. of 1:1 sulphuric acid and 0.6–0.8 ml. of benzaldehyde are added. After stirring, the mixture is placed in a refrigerator for 12 hours. The dibenzal sorbitol is filtered on a tared sintered crucible, washed with water and 50% ethyl alcohol, then dried and weighed. The weight of dibenzal sorbitol multiplied by 0.4791 gives the weight of sorbitol in the quantity of sample taken.

G. STARCH

Various procedures for starch determination have been applied to the analysis of cereals. These include gravimetric and iodimetric methods, measurement of the optical rotation of extracts resulting after digestion with calcium chloride or hydrochloric acid solutions, and measurement of the copper-reducing power of solutions obtained by acid or enzymic hydrolysis. Nicholls[67] states that no reliance can be placed on acid conversion methods for the determination of starch in cacao products owing to the presence of pentosans. Some cellulose also may be converted to sugar.

[66] C. Valencin and J. Deshues, *Bull. Officiel de l'Office Internat. du Cacao et du Chocolat*, *8*, 141 (1938).

[67] J. R. Nicholls, *Aids to Analysis of Foods and Drugs*. 7th ed., Ballière, Tindall and Cox, London, 1952.

Although no true starch is present in cacao shell, Knapp[68] found an apparent starch content of 2.8% in roasted shell when taka-diastase was used as the hydrolysing enzyme. Malt diastase appears to be more selective for starch hydrolysis and it is significant that malt extract is specified by the A.O.A.C.[69] for the first stage in the conversion of cacao starch to sugars, and that an acid-conversion method is described for the determination of "crude starch." Before the above methods can be applied to samples containing sweetening materials, the sugars must be removed by leaching out with water.

Nicholls[70] states that added starch may be estimated microscopically in cacao products by using lycopodium spores as a standard of reference.

TABLE XL. Starch in Cacao Products

	Chocolate liquor	Cocoa powder	Sweet chocolate
Pure starch, %.....	7.77–9.20[a]	8.69–13.46[a]	2.11–4.02[a]
	6.2[b]	10.0[c]	9.17[f]–11.6[e,f]
Crude starch, %.....	11.55–12.48[a]	13.86–18.04[a]	3.17–5.44[a]
	7.0[b]	12–14[b]	4.3–24.3[d,f]

[a] A. L. Winton and K. B. Winton, *The Structure and Composition of Foods*. Vol. IV, Wiley, New York, 1939.
[b] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[c] J. R. Nicholls, *Aids to Analysis of Foods and Drugs*. 6th ed., Ballière, Tindall and Cox, London 1952.
[d] H. E. Cox, *Chemical Analysis of Foods*. 4th ed., Churchill, London, 1950.
[e] A. G. Woodman, *Food Analysis*. McGraw-Hill, New York and London, 1941.
[f] With added starch.

Published data for the starch content of commercial cacao products are presented in Table XL.[71–75]

[68] A. W. Knapp, *Cacao Fermentation*. Bale, Sons and Curnow, London, 1937.
[69] *Methods of Analysis of the A.O.A.C.* 7th ed., Washington, D.C., 1950.
[70] J. R. Nicholls, *Aids to Analysis of Foods and Drugs*. 7th ed., Ballière, Tindall and Cox, London, 1952.
[71] A. L. Winton and K. B. Winton, *The Structure and Composition of Foods*. Vol. IV, Wiley, New York, 1939.
[72] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[73] J. R. Nicholls, *Aids to Analysis of Foods and Drugs*. 7th ed., Ballière, Tindall and Cox, London, 1952.
[74] H. E. Cox, *Chemical Analysis of Foods*. 4th ed., Churchill, London, 1950.
[75] A. G. Woodman, *Food Analysis*. McGraw-Hill, New York and London, 1941.

H. TANNINS AND PIGMENTS

A tentative method for the determination of tannins and pigments in cacao products was published by the Association of Official Agricultural Chemists.[76]

Jensen's method for determination of tannins[77] depends on the use of cinchonine sulphate as precipitant from an alkaline extract. The weight of cinchonine complex multiplied by 0.534 gives the weight of tannin present.

The procedure described by Duthie[78] enables a distinction to be made between tannins and catechin and is therefore useful for following the changes during the curing process.

Twenty-five grams of fresh or fermented kernels are minced and extracted overnight with 220 ml. of cold 40% acetone. The acetone solution is filtered through a small Buchner funnel, using a Whatman No. 41 paper, coated with 2 grams of kieselguhr or other filter aid. The residue is washed with 20 ml. 40% acetone and made up to 250 ml. with water.

Three separate 25-ml. portions of the extract are treated with 150 ml. of saturated cinchonine sulphate. After standing overnight, the liquid is decanted through a Gooch crucible containing a pad of coarse asbestos previously washed with half-saturated cinchonine sulphate and dried at 104°C. The precipitate is washed with half-saturated cinchonine sulphate, dried overnight in a desiccator charged with sulphuric acid and then oven-dried. Jensen's conversion factor, 0.534, is used to calculate the tannin content.

The filtrate is treated with 50 ml. of Stiasny's reagent (100 ml. concentrated hydrochloric acid, 100 ml. water and 150 ml. 40% formaldehyde) and boiled under an air condenser for 1 hour. Any precipitate formed is filtered off, dried and weighed.

As the formation of a second precipitate occurs only when unfermented or partially fermented beans are present, Duthie concludes that it gives a measure of the catechin present. The sum of the tannin and catechin fractions is in reasonable agreement with the total tannin bodies determined by direct precipitation with Stiasny's reagent.

Fincke[79] investigated the red colour produced by boiling cocoa powder under reflux with a solvent consisting of 85 volumes of ethyl alcohol and 15 volumes of concentrated hydrochloric acid. Thaler and

[76] Changes in Methods of Analysis. *J.A.O.A.C., 31,* 78 (1948).
[77] H. R. Jensen, *Analyst, 53,* 365 (1928).
[78] D. W. Duthie, *Analyst, 63,* 27 (1938).
[79] H. Fincke, *Z. Untersuch. Lebensm., 82,* 209, 337 (1941).

Wieseler[80] proposed that colour development might be used as a basis for the quantitative determination of non-fat cacao solids in commercial products. Hallas[81] has shown that the coloration arises from a mixture of components from which cyanidin chloride, liberated by the hydrolysis of anthocyanin and leucoanthocyanin compounds, can be isolated and measured absorptiometrically. For the purpose of studying fermentation changes (see Chapter VI, page 121), he measured the total cyanidin (A) liberated by boiling defatted beans with Fincke's alcoholic hydrochloric acid reagent, the alcohol-soluble cyanidin (B) produced by hydrolysing an alcoholic extract of the beans with hydrochloric acid and the anthocyanin (C) present in unhydrolysed alcoholic extracts. Subsequent procedure for the preparation of solutions used for optical density measurements is summarised below.

Aliquots of filtrates obtained from extractions for A and B are diluted with water. In the case of C, saturated salt solution is used for dilution. The solutions are extracted three times with amyl alcohol and the combined amyl alcoholic extracts are acidified with 1% aqueous hydrochloric acid and shaken with petroleum ether. A quantity of brown insoluble matter is precipitated and the red colour is extracted with successive small quantities of 1% hydrochloric acid until the total volume of acid extracts is 100 ml. 60 ml. (filtered if necessary) are shaken with 25 ml. of amyl acetate. The acid layer is collected in a 100-ml. flask and the amyl acetate layer is extracted with further quantities of 1% hydrochloric acid until the combined extracts total 100 ml. The extract is filtered if necessary and the colour of the clear solution is measured absorptiometrically in a 1-cm. cell, using Chance green No. 5 and blue No. 6 filters in the absorptiometer, against standards prepared from cyanidin chloride. The whole method should be completed as rapidly as possible to avoid interference due to fading.

I. NITROGEN COMPOUNDS

(1) TOTAL NITROGEN

The determination of the percentage of total nitrogen in cacao products calls for no special modification of the Kjeldahl method.

(2) CACAO PROTEIN AND MILK PROTEIN

The percentage of nitrogen due to theobromine and caffeine is calculated and deducted from the percentage of total nitrogen be-

[80] H. Thaler and H. Wieseler, unpublished thesis summarised in *British Intelligence Objective Sub-committee Evaluation Report No. 560.* His Majesty's Stationery Office, London, 1946.

[81] C. A. Hallas, *Unpublished communication.* British Food Manufacturing Industries Research Association, Leatherhead, England.

fore the conversion factor 6.25 can be applied to determine the protein content of cacao products containing no milk solids.

When cocoa is alkalised with an ammonium compound, the nitrogen equivalent of the ammonia present must also be deducted from the total nitrogen content.

The essential features of most of the methods applied to the determination of casein in milk chocolate are similar to the procedure described by the Association of Official Agricultural Chemists. When this method is used, the percentage of total milk protein can be calculated by multiplying the percentage of casein found by 1.07.[82]

Published data for the protein contents of cacao products are shown in Table XLI.[83-85]

TABLE XLI. PROTEIN IN CACAO PRODUCTS

	Chocolate liquor	Cocoa powder	Sweet chocolate	Milk chocolate
Great Britain, [c][a] . .	—	20.4	4.6	7.4
Germany, [c][a]	10.8–11	18–20	4–5	9.5–10.5
U. S. A., [c][f]	12.0–12.9	15.8–18.8	3.3–5.8	—

[a] R. A. McCance and E. M. Widdowson, *Chemical Composition of Foods*. His Majesty's Stationery Office, London, 1942.
[b] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[c] A. L. Winton and K. B. Winton, *The Structure and Composition of Foods*. Vol. IV, Wiley, New York, 1939.

(3) THEOBROMINE AND CAFFEINE

In Section D(1) of this chapter, brief mention is made of a method used for the determination of fat, theobromine and caffeine on the same test sample.

The method (Official, First Action) of the A.O.A.C. is based on a procedure described by Wadsworth[86] for the extraction of theobromine with moist tetrachloroethane.

Lowe[87] claims that extraction can be completed in one hour by continuous treatment with moist tetrachloroethane in a Soxhlet

[82] *Methods of Analysis of the A.O.A.C.* 7th ed., Washington, D. C. 1950.
[83] R. A. McCance and E. M. Widdowson, *Chemical Composition of Foods*. His Majesty's Stationery Office, London, 1942.
[84] H. Fincke, *Handbuch der Kakaoerzeugnisse*. Springer, Berlin, 1936.
[85] A. L. Winton and K. B. Winton, *The Structure and Composition of Foods*. Vol. IV, Wiley, New York, 1939.
[86] R. V. Wadsworth, *Analyst*, *46*, 35 (1921).
[87] E. H. Lowe, *Analyst*, *73*, 679 (1949).

apparatus. The sample is supported in a glass thimble provided with a sintered glass plate covered with a layer of glass wool. A trap is attached to the extraction apparatus for the purpose of collecting excess moisture.

In a simple procedure described by Holmes,[87a] the sample is refluxed with boiling water in the presence of freshly calcined magnesia. The solution is clarified with lead subacetate and filtered. Theobromine is extracted from the concentrated filtrate with chloroform and determined argentometrically.

Moores and Campbell[88] recommend pentane or hexane for defatting samples rich in fat. When using the following process, they obtained results which were in close agreement with analyses by Wadsworth's method. The theobromine contents of a number of samples of expeller cake analysed by them ranged from 1.97 to 2.87%.

Two to three grams of the sample are mixed into a paste with one gram of heavy magnesium oxide and four grams of Celite 545 and extracted by percolation with 500 ml. of boiling water. The filtrate is adjusted to pH = 6.0, concentrated to 150 ml., then clarified with zinc acetate and potassium ferrocyanide and made up to 200 ml. After standing for 3–5 minutes, the precipitate is filtered off and 150 ml. of filtrate are run through a column containing a mixture of equal parts of Celite and fuller's earth.

Save for 4 or 5 ml. kept above the column, the liquid is drawn through in 20 to 40 minutes. 50 ml. of wash water are used, always keeping some liquid above the column during each wash. The theobromine is eluted with 75 ml. of normal sodium hydroxide. The eluate is neutralised with sulphuric acid and the pH is adjusted to 6.4 using 0.025 *N* sodium hydroxide. 25 ml. of 0.01 *N* silver nitrate are added and the solution is titrated electrometrically to pH 6.4. A blank determination is conducted simultaneously.

The percentage of theobromine = $100\ nf/w$, where n is the difference between the titre of sample and blank, f is the theobromine factor and w is the weight of sample clarified. The theobromine factor is $0.18\ Nv/a$, where N is the normality of the sodium hydroxide solution, v = the total volume clarified and a = volume of aliquot analysed. An empirical correction of 3% should be added for adsorption losses due to clarification.

The percentage of caffeine is determined on a separate portion of the sample by the following method:

An extract from 4 grams of sample, prepared in the same manner as described for theobromine, is adjusted to pH 12 and shaken with 5 successive 30-ml. portions of chloroform. At this pH, no theobromine is extracted. The

[87a] K. E. Holmes, *Analyst, 75,* 457 (1950).
[88] R. G. Moores and H. A. Campbell, *Analyt. Chem., 20,* 40 (1948).

chloroform extracts are washed with 5 ml. of *N* sulphuric acid; the acid layer is washed with 50 ml. of chloroform. The chloroform extracts are united in a Kjeldahl flask and after removal of solvent, the nitrogen is determined in the residue by the Kjeldahl-Gunning process.

Moir and Hinks[89] elaborated a method for the determination of "total alkaloids" (theobromine and caffeine) in chocolate cake. It can be applied for the analysis of any foodstuffs containing relatively small quantities of cacao material.

Twenty grams of cake and 2.5 grams of freshly ignited magnesium oxide are rubbed to a smooth paste with alcohol, 80% by volume, transferred to a flask with 200 ml. of 80% alcohol and refluxed for one and a half hours. The extract is filtered by suction and the residue is redigested twice with 100 ml. of 80% alcohol.

The combined filtrates are evaporated to about 100 ml., with addition of some distilled water to replace the alcohol as evaporation proceeds, otherwise the alkaloids are apt to dissolve in the fat. The liquid is acidified with 3 drops of dilute hydrochloric acid and washed into a 200 ml. graduated flask with hot water. If much fat is present, an allowance should be made for its volume. The cooled solution is clarified by the addition of 5 ml. of zinc acetate solution (21.9 grams of zinc acetate cryst. and 3 ml. of glacial acetic acid per 100 ml.) followed by 5 ml. of potassium ferrocyanide solution (10.6%). The mixture is made up to volume with distilled water, filtered, and 150 ml. of the filtrate are evaporated to small bulk and extracted 5 times with 50-ml. portions of chloroform. The extracts are washed and the chloroform is evaporated. The weight of residue is noted as a guide for later treatment. The alkaloids are dissolved in hot water and transferred to a small Kjeldahl flask. 3 ml. of conc. sulphuric acid and 0.1 g. of sucrose are added and the mixture is digested. After frothing has ceased, 0.01 g. of selenium is added and the digestion is continued until half an hour after the liquid has become colourless. The solution is cooled, diluted and neutralised with 2 *N* sodium hydroxide solution and made up to 100 ml. The ammonia present is measured by Nessler's reagent. Convenient standards are prepared from 0.1 to 0.3 ml. of a 0.1% solution of ammonium sulphate.

$$\text{Percentage of alkaloids } (A) = \text{Percentage of nitrogen} \times 3.20$$
$$\text{Percentage of fat-free cacao solids} = 100.A \cdot 3.15$$

The factor 3.20 is based on an average theobromine:caffeine ratio of 9:1 in cacao nibs and the factor 3.15 represents the average percentage of total alkaloids in fat-free dry *blended* cacao nibs. Basic data for nibs analysed by Moir and Hinks are given in Table XI.11.[89]

When using the above method, Parkes and Parkes[90] found that a 5% solution of phenol in chloroform facilitated extraction of the

[89] D. D. Moir and E. Hinks, *Analyst*, **60**, 439 (1935).
[90] A. E. Parkes and H. A. Parkes, *Analyst*, **62**, 791 (1937).

alkaloids. The phenol is later removed by gentle warming in a current of air.

In Harral's method[91] theobromine is converted into caffeine by means of alkali and methyl sulphate in the presence of sugar, and the alkaloids are extracted in the form of caffeine, which is more readily soluble than theobromine.

TABLE XLII. "Total Alkaloids" in Roasted Cacao Nibs[a]

	Moisture, %	Fat, %	"Total Alkaloids," % in original	"Total Alkaloids," % in dry fat free
Accra	2.15	55.7	1.42	3.37
Java (Criollo)	2.65	54.0	1.37	3.16
Bahia	2.25	53.8	1.35	3.07
Samoa (Criollo)	3.75	55.6	1.29	3.17
Trinidad	3.10	55.7	1.30	3.16
Grenada	3.01	55.9	1.11	2.70

[a] D. D. Moir and E. Hinks, *Analyst, 60,* 439 (1935).

TABLE XLIII. Theobromine and Caffeine in Cacao Products

	Chocolate Liquor	Cocoa Powder	Sweet Chocolate	Milk Chocolate
Theobromine, %[a]	1.5	2.5 –2.7	0.7 –0.9	0.15–0.40
Theobromine, %[b]	0.71–0.90	0.85–1.57	0.30–0.43	—
Caffeine, %[b]	0.04–0.33	0.09–0.19	0.03–0.14	—

[a] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[b] A. L. Winton and K. B. Winton, *The Structure and Composition of Foods.* Vol. IV, Wiley, New York, 1939.

Published data by Fincke[92] and Winton and Winton[93] for the theobromine and caffeine contents of cacao products are given in Table XLIII. Winton and Winton quote rather old analyses. The higher theobromine values given by Fincke may be accepted as being more representative of present-day products.

J. METALLIC IMPURITIES

Standard methods for the determination of metallic impurities can be applied to cacao products without any special modifications.

[91] J. C. Harral, *Analyst, 65,* 408 (1940).
[92] H. Fincke, *Handbuch der Kakaoerzeugnisse.* Springer, Berlin, 1936.
[93] A. L. Winton and K. B. Winton, *The Structure and Composition of Foods.* Vol. IV, Wiley, New York, 1939.

K. CARBON BLACK IN CHOCOLATE

The following method has been used by Sidaras[94] for the detection of carbon black in chocolate.

The defatted residue from 100 grams of chocolate is digested with two portions of 100 ml. of 16 *N* nitric acid until brown fumes cease to be given off. The mixture is diluted with 100 ml. of water and filtered and washed. If the residue is grey or black, the presence of carbon is indicated. The residue is acetylated with a mixture of acetic anhydride 75 parts, acetic acid 75 parts and sulphuric acid 10 parts. After acetylation, which may take several hours, 75 ml. of acetic acid are added and the carbon is filtered off on a Gooch crucible and washed with acetic acid and later with chloroform. The crucible is dried at 120°C., weighed, ignited and reweighed. The difference in weight is due to carbon.

L. MEASUREMENT OF PARTICLE SIZE

Sedimentation and microscopical methods are suitable for the estimation of the size of particles in chocolate and cocoa.

Measurement of particle size by sedimentation is based on the assumption that when a uniformly dispersed suspension is allowed to settle, the particles move freely and obey Stokes' law for falling spheres. Andreasen[95] demonstrated that Stokes' law could be applied to angular particles of the same weight as spheres.

Within a distance h cm. from the surface, after an interval of time t minutes, only those particles whose speeds are less than h/t cm. min. will be present. The maximum size of particles at a given time t can be calculated from the equation[96]

$$d_t = 175 \sqrt{\frac{\eta h}{(\sigma - \rho)t}}$$

where d_t = Stokes' diameter in μ
t = time in minutes
h = height of suspension in cm.
η = viscosity in poises
σ = density of powder in g./cc.
ρ = density of fluid in g./cc.

[94] A. P. Sidaras, *J.A.O.A.C., 32,* 135 (1949).
[95] A. M. H. Andreasen, *Kolloid-Z., 48,* 175 (1929).
[96] D. G. Skinner, S. Boas-Traube, R. L. Brown and P. Hawksley, *Determination of Particle Size in Sub-sieve Range, Part II.* The British Colliery Owners Research Association and the British Coal Utilisation Research Association, 1942.

Andreasen's sedimentation apparatus is a jacketted cylinder of 600 ml. capacity and 6 cm. diameter, fitted with a sampling tube reaching to a distance h below the surface of the liquid. To the upper end of the tube a pipette is attached for the withdrawal of 10 ml. portions of fluid by suction. Blank tests with water are made to determine h, which decreases as t increases.

Ethyl phthalate is a suitable dispersing medium for cacao material. Whereas 5 grams of sample is a convenient amount for dispersal, greater precision is obtained with smaller portions, as the method suffers from the disadvantage that some of the smaller particles are carried away with the coarse ones. When the size of the sugar particles is required, the sugar content of the withdrawn fluid can be determined.

A microscopical method,[96a] dependent on lycopodium counts, has been applied by Mason[97] for estimation of the size of both cacao and sugar particles. The object is to find the number of sugar or cacao particles of some definite size and the number of lycopodium spores in an equal number of fields.

A graticule ruled in 0.5-mm. squares is placed in the eyepiece of a microscope. Lenses and drawtube are adjusted so that 25 on the eyepiece scale is represented by 0.05 mm. on the stage micrometer when smaller particles are being counted. When larger particles are being counted, the microscope is adjusted so that 100 on the eyepiece scale is represented by 0.1 mm. on the stage micrometer.

For cacao particle counts, 2.5 g. of chocolate are defatted, 0.1 g. of lycopodium is added and the mixture is dispersed in 8 ml. of water and 2 drops of 2 N sodium hydroxide.

For sugar particle counts, 0.5 g. of chocolate and 0.1 g. of lycopodium spores are dispersed in 10 ml. of mineral oil. The suspension is well shaken before preparation of the slides.

Smaller particles are counted by placing one drop of the dispersion on a slide, covering it with a $^{7}/_{8}$-in. cover glass and examining 10 fields. Lycopodium spores and sugar particles are counted on the same field.

Larger particles are counted in 6 or 7 drops of dispersion placed between 4-inch smooth squares of plate glass. Ten fields are examined for lycopodium and 40 for sugar particles of 50–100 μ and upwards.

The weight of 100 lycopodium spores is 1.064×10^{-6} gram. In a mixture of 0.5 g. of chocolate and 0.1 g. of lycopodium, 100 lycopodium spores correspond to a weight of 5.32×10^{-6} gram of chocolate.

If n = the number of sugar particles equivalent to 100 lycopodium spores, then the number of particles per gram of chocolate

[96a] T. E. Wallis, *Pharm. J., 103,* 75 (1919).
[97] H. M. Mason, *Analyst, 58,* 440 (1933).

is 188,000 n. It is convenient to make calculations in units of 100,000 particles. The number of such units per gram of chocolate is 1.88 n.

Results are expressed in terms of the number of units of 25 μ particles which would be present if the larger particles were reduced to this size, thus a particle of 100 μ diameter represents 64 and a particle of 50 μ diameter represents 8 particles of 25 μ diameter. Mason describes this form of presentation as the *micro* value, which is a measure of the coarseness of the chocolate.

It is necessary to subtract n_1, the number of 100 μ units from n_2, the number of 50 μ units before the latter can be calculated to the equivalent number of 25 μ units and n_3, the number of 25 μ units must be corrected in a similar manner.

The micro value is therefore

$$64\ n_1 + 8(n_2 - n_1) + (n_3 - n_2)$$

or, in simplified form

$$56n_1 + 7n_2 + n_3$$

The following micro values, in respect of sugar particles were observed by Mason for different degrees of chocolate refinement: very coarse 167.0, coarse 116.8, medium 101.5, fine 51.5 and superfine 16.3.

The calculation for cacao particles differs only with respect to the chocolate equivalent of 100 lycopodium spores, owing to the larger weight of chocolate taken.

CHAPTER XII

THE COCOA AND CHOCOLATE INDUSTRY

1. Cacao-producing Countries

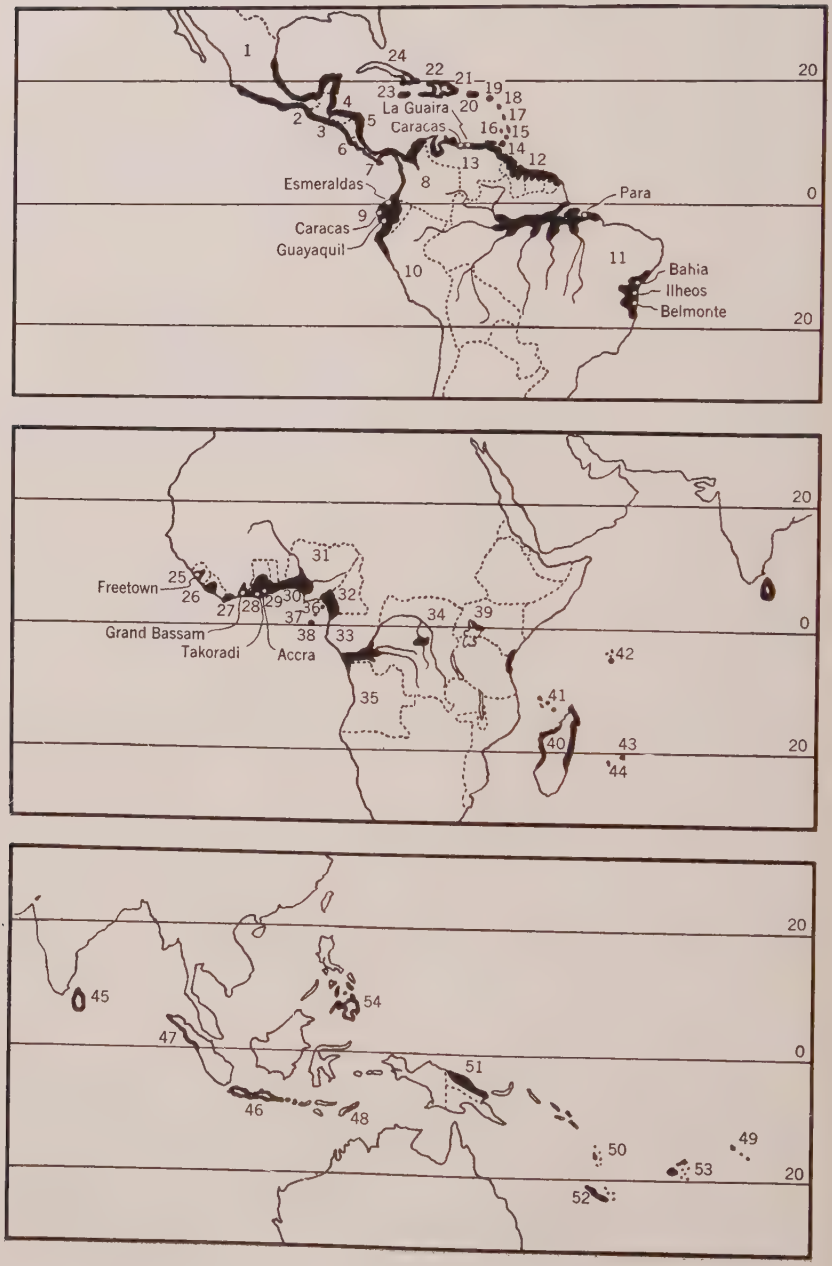
Cacao is grown mainly for export. Only a small proportion of the world output is manufactured for consumption in the countries where the crops are produced. This is especially the case in territories where the introduction of cacao is of comparatively recent date. The output of chocolate confectionery for domestic consumption in the older production areas is increasing and small quantities are exported from some of the Latin-American countries.

Raw cacao is usually marketed under the names of the districts where the crops are located or it may be differentiated according to the principal ports of shipment. The local name has come to be regarded as an index of the quality of the beans, although it is not necessarily related to any particular botanical variety. Further distinction may be made between main and secondary crops. The quality of the former is likely to be superior owing to better harvesting conditions.

The geographical distribution of cacao is represented by the areas shown in black on the accompanying map (Fig. 30). With the exception of a few areas of minor importance, producing countries are indicated by numbers which are explained in the legend. For the convenience of the reader, these reference numbers also appear in parentheses when the industry of each country is described in the following account.

A. CENTRAL AMERICA

Mexico (1) is the most northerly cacao-producing country. In the sixteenth century, the industry was well developed by the standards of the time and it was from there that the first cacao beans were exported to Europe. More recently, the entire crop was consumed within the country and beans were imported from Ecuador to meet the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Grand Bassam
Takoradi
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Fig. 30. Geographical distribution of cacao production. The principal cacao growing countries are shown in black.

1 Mexico
2 Guatemala
3 Salvador
4 Honduras
5 Nicaragua
6 Costa Rica
7 Panama
8 Colombia
9 Ecuador
10 Peru
11 Brazil
12 Surinam
13 Venezuela
14 Trinidad
15 Grenada
16 St. Lucia, St. Vincent
17 Martinique
18 Dominica
19 Guadeloupe
20 Puerto Rico
21 Dominican Republic
22 Haiti
23 Jamaica
24 Cuba
25 Sierra Leone
26 Liberia
27 Ivory Coast
28 Gold Coast
29 Togoland
30 Dahomey
31 Nigeria
32 Cameroons
33 French Equatorial Africa
34 Belgian Congo
35 Angola
36 Fernando Po
37 Principe
38 San Thomé
39 Uganda
40 Madagascar
41 Comoro
42 Seychelles
43 Mauritius
44 Réunion
45 Ceylon
46 Java
47 Sumatra
48 Timor
49 W. Samoa
50 New Hebrides
51 New Guinea
52 New Caledonia
53 Fiji
54 Philippine Islands

demands of the industry. During the past five years there has been a considerable expansion in production. In 1947, as a result of accumulated stocks, Mexico again became an exporting country for the first time since 1925 and supplied about 4500 tons of cacao to the United States. Exports were insignificant in 1948 and 1949. It was estimated that the 1950 crop would surpass the 1947 record production of 7000 tons.

Domestic consumption accounts for some 5000 tons of cacao annually. Of this, 2000 tons are absorbed by two factories making cocoa butter.

In 1933 there were 12,000 acres under cacao, mainly in the state of Tabasco. Acreage has now been increased to 48,000 and there are promising areas for expansion in the states of Campeche and Veracruz.

The main crop is harvested between April and August and the secondary crop between September and March. Approximately 40% of the crop is pure Criollo. Mexican beans are above the average in size and are characterised by a mild flavour and aroma.

At the time of the Spanish conquest, cacao was cultivated by the Mayas in Guatemala (2).[1] Production in recent times has been on a small scale but it is now assuming greater importance. There has been an expansion of acreage during the past ten years. Exports increased steadily between the years 1936 and 1943 and reached a volume of 350 tons (more than half of the total crop) in 1948, when the bulk went mainly to the United States. Exports in 1949 were chiefly to El Salvador. Cacao is grown under high and heavy shade. The beans are mainly near-white varieties requiring only a short fermentation.

Production in El Salvador (3) and Honduras (4) is comparatively unimportant. Exports are negligible and cacao is imported from Ecuador. British Honduras, which lies to the east of Guatemala, produces some cacao. The crop grows on land up to 1500 ft. above sea level and consists of Forastero Trinitario with an admixture of Criollo.

In Nicaragua (5), cacao is grown in the south west, between Nicaragua Lake and the Pacific. Owing to seasonal drought between December and April, plantations are irrigated. The mean

[1] I. Erneholm, *Cacao Production of South America.* Holmqvists Boktryckeri A. B., Gothenburg, 1948.

annual rainfall is 45 inches. Mango trees are used as windbreaks. Because of the wide spacing (15 x 15 ft.) a high proportion of shade trees is required. The crop consists of very large Criollo beans with a mild flavour and is harvested in November and December. Exports in the peak year (1938) were 576 tons. Production has since declined to less than 250 tons annually. A plantation was established in Nicaragua by the firm of Menier (France).

In Costa Rica (6) cacao has been cultivated for 200 years along the Caribbean and Pacific coasts. Production rose steadily between 1920 and 1930, as a result of plantings to replace banana crops destroyed by Panama disease and 40,000 acres are now in production, chiefly in Limon province. About half of the plantations are owned by the United Fruit Company. Further expansion by planting high-yielding strains is contemplated. On account of the high annual rainfall of 120 inches, the crop suffers from pod rot. Witches' broom and Monilia diseases (see Chapter IV, 4B and 4C) are not known in Costa Rica. The main crop is harvested between October and January and the secondary crop from May to July. The beans are a near-Criollo variety and have a mild flavour. Shipments are made from Port Limon.

A Cacao Center has been established at Turrialba for the exchange of information, research work and training of students. The American Cocoa Research Institute is co-operating in an effort to solve problems connected with cacao culture.

In Panama (7), as in Costa Rica, cacao was planted between 1910 and 1920 after losses of banana crops through Panama disease. Some 22,000 acres are now under cultivation, mostly owned by the United Fruit Company.

B. SOUTH AMERICA

Towards the close of the 19th century, South American cacao accounted for 50% of the world supplies.

After a recent period of steady decline in the continental output, mainly caused by the abandonment of plantations where *Marasmius* (witches' broom) and *Monilia* (see above) are rife, concerted efforts are now being made to rehabilitate the cacao industry.

For a full account of the history, economics and ecology of cacao

in South America, the reader may consult a recent authoritative work by Erneholm.[2]

Cacao is probably indigenous to Colombia (8)[3] and has been cultivated there for over two centuries. Formerly, a fine grade of cacao was exported from Cartagena. The entire crop is now absorbed by the chocolate factories which have been established in the country. Although cacao production expanded from 9000 tons in 1943 to approximately 11,000 tons per annum, an increasing tonnage is imported from Ecuador and Brazil to meet the demands of the country.

Cacao is cultivated in the interior, chiefly in the Cauca valley, where Criollo is grown at altitudes of 3000 ft. and upwards on volcanic ash, and at lower levels in the Magdalena valley. In the rain forests of the Amazon and Orinoco tributaries, where Amazon Forastero and Orinoco Trinitario are grown, the trees are infected with *Marasmius*.

A research station for the study of high altitude cacao has been established at Palmira in the Cauca valley and a sub-station is functioning in the Zona Bananera a little above sea level.

Cacao appears to have been cultivated in Ecuador (9) at the time of the expedition of Pizarro[4] in 1526–27 and the earliest exports from Guayaquil went to Central American destinations. From the beginning of the 18th century, monoculture of a fine grade of cacao (Nacional) persisted until the close of the 19th century by which time Trinitario introductions from Trinidad, Colombia and Venezuela were yielding heavy crops and exports were mounting rapidly. The record crop was harvested in 1916, when exports amounted to 50,000 tons. For many years, Ecuador was the main exporting country, until it was surpassed by Brazil in 1906. Ecuador regained the lead for one year in 1910. A decline in production, due to the incidence of *Monilia* in 1918 and *Marasmius* a few years later, resulted in the neglect of plantations, particularly of Trinitario cacao, and by 1931, the volume of exports was reduced to one-third of the 1916 peak. In districts where river transport is accessible, replantings mainly of

[2] I. Erneholm, *Cacao Production of South America*. Holmqvists Boktryckeri A. B., Gothenburg, 1948.

[3] F. J. Pound, in *Report and Proceedings of the Cocoa Research Conference 1945*. Colonial No. 192. His Majesty's Stationery Office, London, 1945.

[4] I. Erneholm, *Cacao Production of South America*.

Trinitario are proceeding, but more remote infected areas have become derelict.

The rich alluvial soil, annual rainfall and uniform shade temperature throughout the year are natural conditions suited to cacao cultivation, but the high humidity favours fungus diseases.

In the high-lying Arriba district of the province of Los Rios, cacao cultivation is concentrated along the Guayas tributaries and accounts for two-thirds of the total Ecuadorian crop.

In Guayas province, which lies to the south of the river of the same name, cacao is grown in the coastal areas. The bulk of Ecuador cacao is shipped from the port of Guayaquil and the beans are sometimes described as "Guayaquil" cacao.

Yields have been reduced in the province of El Oro, owing to the onset of disease. About 30% of the country's crop is grown there and is known commercially as Machala cacao.

Some cacao is grown in the Chone district of the province of Manabi and shipped from the port of Bahia de Caraquez. Commercial cultivation has been practically abandoned in the province of Esmeraldas. A wild Criollo type grows there.

Bananas, cassava and maize are used for temporary shade and erythrinas (immortelles) are planted for permanent shade.

The "Cacao Nacional" of Ecuador has always been renowned for its flavour and commands a good price, despite the fact that it is often fermented under somewhat haphazard conditions. Greater uniformity may be expected as a result of research work at the Cooperative Agricultural Station near Guayaquil which is organised in conjunction with the U. S. Department of Agriculture.

Exports reached their lowest level of recent times in 1940 (11,000 tons) and rose to almost 17,000 tons in 1945. In 1947 and 1948 just over 20,000 tons were exported. Eighty per cent of the total amount exported goes to the United States. Colombia is the next best customer, absorbing about 7.5%. Most of the rest goes to Europe.

There are some cacao plantations in Peru (10) and many wild trees occur in the forest areas. Production is on a small scale and is consumed locally. Cacao beans, cocoa and chocolate are also imported. A little cacao is grown in the neighbouring country, Bolivia.

While cacao cultivation has been declining in other Latin-American countries, production has increased steadily in Brazil (11), particularly in the state of Bahia where old trees have been replaced by higher-yielding varieties.

Before the Gold Coast took the lead, Brazil was the most important cacao-producing country and now occupies second place. Some 500,000 acres are in production.

Although a considerable amount of cacao is processed in Brazil, especially for the production of cocoa butter and expeller cake for theobromine extraction (see Table XLIV)[5] more than 90% of the crop is exported. The chief markets are the United States and the Netherlands. Approximately 96% of the country's total output of cacao comes from the state of Bahia, where it is grown on a coastal strip some 200 miles long and seldom more than a few miles wide.

TABLE XLIV. Brazilian Output of Cacao and Cacao Products (metric tons)[a]

	1947	1948
Beans for export	99,041	71,681
Chocolate liquor	2,615	355
Cocoa butter	4,024	3,522
Press cake	1,440	2,225
Chocolate	1,105	15
Other products	60	—

[a] Anon., *Internat. Choc. Review, 4,* 364 (1949).

Cultivation is most concentrated in Ilheus district where 70% of the Bahia crop is grown on shallow compact soil derived from gneiss and mica schist with granite intrusions. The soil in Itabuna district is similar. Erneholm[6] predicts a decline in production unless fertilisers are used to improve the status. In Belmonte district, the soil is alluvial. As a rule, plantations are large and they lie between 300 and 1000 feet above sea level. The crop consists almost exclusively of an ordinary grade of Forastero, known commercially as Bahia cacao, which is shipped from Salvador, Ilheus and Belmonte. In recent years, transport has been improved by the construction of new roads to the ports. The industry is hampered by an acute labour shortage.

A superior grade of cacao, known by the local name Para, is produced in the Lower Amazon basin and shipped from the port of Para.

There is no well-defined dry season in Brazil. The mean annual

[5] Anon., *Internat. Chocolate Rev., 4,* 364 (1949).
[6] I. Erneholm, *Cacao Production of South America.* Holmqvists Boktryckeri A. B., Gothenburg, 1948.

rainfall is 75 inches and ranges from 80 inches in Ilheus to below 50 inches in other districts. Mean shade temperatures are highest in Para district and average 75°F. Relative humidity is in the neighbourhood of 85%.

The main crop is harvested between September and January and the secondary crop between April and August.

In Bahia, the crop suffers from thrips attack (see p. 69). Leaf-cutting ants cause appreciable damage in Ilheus, Itabuna and Rio Nova areas. Cacao is inspected and graded by the Instituto Caucau de Bahia which for the past 20 years has maintained a research station at Urucuca. The Institute's marketing monopoly came to an end in 1946.

About 500 acres of cacao are in bearing in British Guiana. Cultivation began at the end of the 17th century and was developed in the 19th century but has never assumed importance. Pre-war exports from French Guiana amounted to about 20 tons, but are now negligible. The French Government is organising the rehabilitation of the plantations (approximately 500 acres). The neighbouring island of Cayenne has some 60 acres planted with cacao which yields from 10 to 12 tons of excellent beans.[7]

Cacao cultivation commenced in Surinam (12) at the end of the 17th century and exports from there went to Spain in 1702. At the beginning of the 19th century some 350 tons were exported annually. In the peak year (1895) over 4000 tons, constituting 5% of the world output, were exported. Particular attention was paid to irrigation and dykes were constructed to protect the plantations from inundation by tidal rivers. Serious attacks by witches' broom, which was first observed in this country, caused a steady decline in production. A high proportion of the surviving trees was destroyed by drought in 1925. Plans for rehabilitation are now going forward. New introductions are being made with resistant Trinidad stock.

From the beginning of the 18th century to the middle of the 19th century, Venezuela (13) was the most important cacao-producing country and still excels in the output of quality grades of fine Criollo and Forastero beans. The crop consisted chiefly of Criollo until 1821, when 4000 plants were imported from Trinidad. To distinguish these introductions from the local trees they were called *Forastero*

[7] L. J. Schwarz in *Cocoa Conference 1948*. The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1948.

(foreign) or *Trinitario* after their country of origin. These names have survived and are universally used in the classification of cacao.

Plantations are situated in the Caribbean littoral, along the Orinoco tributaries and Maracaibo lake and in the Puerto Cabello district and often contain mixed populations of Criollo and Forastero trees. Some 130,000 acres are now planted and yield 400 lb. of dry cacao per acre.[8]

Although most of the plantations lie 1000 ft. above sea level, some cacao is cultivated at high altitudes (3000 ft.). Mean shade temperatures are 77°F. or even higher and the evenly distributed annual rainfall ranges from 40 to 60 inches according to the district.

In the Maracaibo and Puerto Cabello areas, trees are mainly Criollo. Elsewhere Trinitarios predominate. Bananas and maize are used for temporary shade and erythrinas, sometimes mixed with *Tabebuia pentaphylla,* supply permanent shade. Mixed shade has been introduced as a safeguard in districts where erythrinas have succumbed to an obscure disease causing dieback.[9]

The main crop is harvested between November and February and the light crop between April and June. Local names for Venezuelan cacao are Caracas, Carupano, Maracaibo and Puerto Cabello according to the port or district. Some grades of beans are clayed (see p. 107).

Exports were highest in 1925, when 23,000 tons were shipped. Cacao then accounted for 16.5% of the overseas trade of the country. Thereafter production declined and exports were halved by 1947.[10] Despite the stimulus given to the trade by the offer of an export bounty by the government, 25,000 acres have been abandoned since 1936,[11] mainly as a result of infection by *Monilia* and witches' broom, especially in older areas of cultivation, and partly through the diversion of labour to the oilfields.

Cacao is shipped from the ports of Caracas, Carupano and La Guayra. During the period 1935–39, half of the exports went to the United States and the other half to Europe. In 1947, only 14.3% were destined to Europe and almost the whole of the remainder to the United States. In 1949, Belgium was the second-best customer.

[8] Anon., *Internat. Chocolate Rev., 4,* 293 (1949).
[9] A. F. Posnette and L. Palma, *Trop. Agric., Trinidad, 21,* 130 (1944).
[10] I. Erneholm, *Cacao Production of South America.* Holmqvists Boktryckeri A. B., Gothenburg, 1948.
[11] Anon., *Internat. Chocolate Rev., 4,* 293 (1949).

C. WEST INDIES

Cacao was introduced into the West Indies shortly after the Spanish conquest. In recent years, soil exhaustion and prevalence of disease have brought about a decline in production in most of the islands. There is some hope of improved yields in the near future through the multiplication and distribution of resistant and high-yielding strains.

A high grade of Forastero cacao has been exported from Trinidad (14) during the past 130 years. In the year 1920, there were 325,000 acres under cultivation. The average annual output for the period 1920–24 amounted to 28,370 tons. By 1944, the area under cacao had been reduced to 180,000 acres and exports had dwindled to 5000 tons. Losses by disease have been the main cause of the decline. Soil exhaustion appears to have been a contributory factor. Soils have now been graded according to their productivity (see p. 40). Table XLV shows the respective areas of Grades I, II and III

TABLE XLV. Distribution of Soil Grades in Trinidad and Tobago[a]

	Trinidad		Tobago	
Grade	Acres	Soil type	Acres	Soil type
I	4,480	Glauconitic limestone	5,120	Igneous and calcareous
II	51,200	Mainly calcareous	2,500	Mainly calcareous
III	102,400	Silty clays	2,500	Loams and clays

[a] E. M. Chenery in *Report and Proceedings of the Cocoa Research Conference 1945.* C.P. 18, Colonial No. 192. His Majesty's Stationery Office, London, 1945. (Tabulated from information in the text.)

soils in Trinidad and the neighbouring island of Tobago.[12] In Trinidad, some cacao is produced on still lower grades of soil. Plantings in Tobago are of more recent date and low grades have been avoided.

Formerly, most of the Trinidad crop came from well-managed estates supporting 300 trees per acre. Many of the plantations have now been split up into smaller holdings.

Rainfall is on the low side and humidity is high, even in the dry season. The rainy season extends from July to December. The main harvest is collected between November and February. The beans

[12] E. M. Chenery in *Report and Proceedings of the Cocoa Research Conference 1945.* Colonial No. 192. His Majesty's Stationery Office, London, 1945.

are usually of "quality" grade and they are "danced" (see p. 108), to give them a high polish. Claying (see p. 107) is now prohibited.

Bananas, cassava, etc. are used for temporary shade. *Erythrina glauca* known locally as Bocare immortelle and *Erythrina poeppigiana* (Anauca immortelle) which are used for permanent shade, suffer from fungus diseases associated with *Calostilbe striispora*. The suitability of other leguminous plants as substitutes for immortelles, especially Bocare which is susceptible when 30 years old, is now being investigated.[13]

The Imperial College of Tropical Agriculture, established in 1921, and the Department of Agriculture are cooperating in research work on every aspect of cacao cultivation.

Cacao is the principal export crop of Grenada (15). High quality grades are grown on the estates. About half of the crop comes from small holdings. Approximately 28,000 acres are in cultivation. The trees are closely planted (400 per acre) and no shade is provided. Fertilisers are applied for the upkeep of the soil. Although no serious diseases have been reported, exports have declined from 5000 to 4000 tons in recent years. The main crop is harvested between October and March and the light crop from May to July.

Hart[14] described cacao agriculture in Grenada as a more careful orchard cultivation than is found in any other country where cacao is grown.

Disease, hurricanes, low market prices and competing crops have resulted in a decline in cacao production on the British Windward Islands, St. Lucia and St. Vincent (16). Methods of cultivation in St. Lucia are similar to those of Trinidad. In the past 40 years, annual exports have declined from 900 to 200 tons. St. Vincent produces about 100 tons of cacao per annum.

Cacao has been cultivated in the French colony Martinique (17) since 1660 and supplies were absorbed by the chocolate industry in France. Production has declined during the present century and the entire crop is now consumed locally. As in St. Vincent, hurricanes have taken their toll and cacao has been replaced by more lucrative crops. Similar causes have contributed to the reduction of exports from Dominica (18) and Guadeloupe (19).

Puerto Rico (20) exports only a few tons of cacao annually.

[13] C. A. Thorold, *Trop. Agr. (Trinidad), 21,* 130 (1944).
[14] J. H. Hart, *Cacao.* Duckworth, London, 1911.

It is now 200 years since cacao was introduced into the Dominican Republic (21) where it is grown mostly on small farms and sometimes without shade. After a long period of stagnation, the industry expanded considerably during the early years of the present century. Production has since been maintained at a fairly steady level and is now on the increase. While no serious outbreaks of disease have occurred, occasional havoc has been caused by hurricanes.

Primitive methods of cultivation are fairly general. In the 185,000 acres devoted to cacao, 50% of the trees are between 25 and 50 years old. Medium grades of Forastero cacao are produced including the ordinary type known by the name of Sanchez. The main crop accounts for 60% of the total yield and is harvested between March and June. The light crop is collected in November and December. The United States is the chief customer both for the raw beans and chocolate which is processed in the country. The chief ports are Sanchez, San Domingo and Samana.

The Dominican Republic ranks sixth in importance as a cacao-producing country. Annual exports averaged 23,000 tons between 1934 and 1944. In 1948–49 an all time record of 30,000 tons was exported.

In the neighbouring country of Haiti (22) the cultivation of cacao is declining. Many of the trees have reverted to the wild state. By comparison with the Dominican Republic exports are unimportant and have seldom exceeded 3000 tons annually. The average for recent years is below 1500 tons.[15]

Cacao was planted in Jamaica (23) by the colonising Spaniards. After years of continued progress, the plantations were wiped out by hurricanes. When the island became a British possession, replantings were made in sheltered valleys. Annual production between 1910 and 1920 averaged 3000 tons and has now shrunk to 2000 tons as a result of the competition of the banana crop. In view of the incidence of banana disease, a plan has been drawn up for the rehabilitation of the cacao industry by replanting with Criollo and Trinitario types, interspersed with bananas for shade. A survey has shown that large tracts exist which would be suitable for cacao.[16]

[15] E. G. Montgomery and A. M. Taylor. *World Trade in Cocoa.* Industrial No. 71, U. S. Department of Commerce, U. S. Govt. Printing Office, Washington, D. C., 1947.

[16] J. Wright, *The Resuscitation of the Cocoa Industry in Jamaica.* Department of Agriculture, Jamaica, Extension Circular No. 7 (1949); *Nature, 164,* 306 (1949).

The two harvests in Jamaica are from September to February for the main crop and from April to June for the secondary crop.

Most of the cacao grown in Cuba (24) is raised on small farms. Exports reached their maximum volume (over 3000 tons) in 1906. The bulk of the crop (about 6000 tons) is now consumed on the island and cacao is sometimes imported. Although the soil and climate are favourable on the whole, the country is subject to periods of drought and hurricanes. The main crop is harvested between November and January and the light crop between April and June.

D. AFRICA

The major crops of African cacao are produced in the heavy rain forest lands bordering the Gulf of Guinea, where climatic conditions are eminently favourable. During the 17th and 18th centuries, cultivation was confined to the islands and did not spread to the mainland until the latter part of the 19th century.In the early years of the 20th century a tremendous expansion was witnessed. By 1919, the tonnage of African exports had surpassed that of South and Central America. In the next two years the outputs were almost equal and thereafter the African lead was firmly established. Notwithstanding the inroads made by disease, the African superiority in tonnage is still maintained and accounts for more than 60% of the world output at the present time.

Cacao is an unimportant crop in Sierra Leone (25) where it is grown in coastal districts. Small quantities are exported from the port of Freetown.

A few hundred tons of cacao are exported annually from Liberia (26). The crop is grown under government supervision and grading laws are now in force. About 3000 acres are under cacao. Recent developments, planned with the assistance of the United States Government Mission, include the planting of one million trees during 1947 and 1948, with the aim of producing 50,000 tons of cacao annually by 1957.

The development of the French West African cacao trade is illustrated by the enormous increase in production between the years 1920 and 1938. Exports from the individual French colonial and mandated territories at the beginning and end of this period are compared in Table XLVI.[17]

[17] A. Balleyguier in *Cocoa Conference 1949*. The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1949.

Similar climatic conditions to those of the British West African colonies prevail in the Ivory Coast (27), which now ranks fourth in importance as a cacao-growing country. Lack of man-power was the main cause of a decline in production during the second world war. By 1945, exports were approximately 30% below the pre-war level. Owing to rehabilitation and favourable weather conditions, the 1948–49 crop surpassed all previous records.

TABLE XLVI. Cacao Production in French West Africa (metric tons)[a]

	Ivory Coast and Dahomey	Cameroons and Gabon	Togo	Total
1920.....	1,000	4,100	2,600	7,700
1937/38.....	50,000	29,900	7,200	87,100

[a] A. Balleyguier, in *Cocoa Conference 1949*. The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1949.

The cacao farms and plantations occupy an area of 250,000 acres. All land is owned by the Government and is rented, mainly in small units, to native farmers. Many of the trees are now overage and must be replaced if production is to be maintained. The farmers are encouraged to rehabilitate their plantations by receiving a bonus from the French Government for replanted acreage. Measures are being taken to combat swollen shoot disease (see p. 64) which has caused less havoc in the Ivory Coast than in British West Africa. The re-establishment of grading regulations has resulted in an improvement of bean quality. Some progress has been achieved in road construction, but transport facilities are not yet adequate.

The main harvest is gathered from September to December and the light crop in May and June.

Purchases of beans for export are made through a marketing board acting on behalf of the French Colonial Office. More than half of the crop goes to metropolitan France, about 20% to the United States and the remainder is destined to European countries. Hitherto, the bulk of the tonnage has passed through the port of Grand Bassam, where it was shipped from surf boats. Improved facilities will shortly be available at the new port of Abidjan.

The French colony Dahomey (30) has never been an important cacao producer. The exports, which are insignificant, are included with those of the Ivory Coast in the official returns for French West

Africa. French Togoland (29) now produces only about 2000 tons of cacao annually. In 1937–38, 7000 tons were exported.

The spectacular rise of cacao production in the Gold Coast (28) and Nigeria (31) is illustrated by the accompanying chart (Fig. 31).

Plantings on a small scale began in 1887 in the high rain forest areas behind the coastal grasslands of the Gold Coast. Thereafter expansion proceeded at an astonishing rate and the annual production surpassed that of Brazil in 1911. Since then, the Gold Coast has maintained its lead as the major cacao-producing country. The output reached its zenith in 1936, when 42% of the world's supplies were exported. In 1947, 60% of the country's exports consisted of cacao. Over one million acres are planted with cacao, most of which is

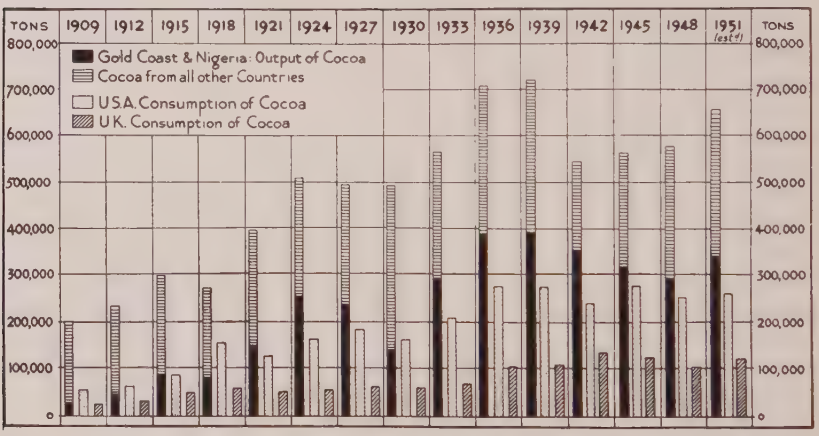

Fig. 31. World cocoa output and uptake by U. S. A. and Great Britain. (By permission of Cadbury Bros., Ltd.)

grown by peasant farmers (Fig. 32) on land owned by the tribal communities. The farms are distributed along the hillsides in the Eastern and Western Provinces of the Colony, Ashanti and British Togoland. There is no orderly spacing and in the older areas, cacao is frequently mixed with other food plants. Silk-cotton, kapok and plantain are used for shade.

Most of the cacao is a filler type of Amazonian Forastero, known as Amelonado. The trees attain a height of 15–25 feet and the pods are easily harvested as they grow on the lower parts of the tree. Over 90% of the crop is harvested between August and February.

The light crop is gathered between April and July. The beans are medium-sized and have a mild, acid flavour.

Between the years 1937 and 1945, production declined gradually at first, and then more rapidly owing to the spread of disease and, to a smaller degree, through soil exhaustion.

It is estimated that there were about one and a half million acres in bearing in 1932 and that the number of cacao trees was in the neighbourhood of 400 million. By 1939, swollen shoot disease (see p. 58) was killing one million trees annually. The annual death rate had risen to 5 million in 1945 and rose to 15 million in 1947. Some 47 million trees were then judged to be infected and likely to die by 1949. The Eastern Province, formerly the most productive area,

Fig. 32. Postage stamp showing Gold Coast cocoa farmer harvesting pods. (By permission of the Crown Agents for the Colonies.)

was the first part of the country to be affected. The disease then spread to Ashanti. In the Western Province, attacks are only sporadic.[18] Shade trees, likewise, are hosts for mealybugs, the insect vectors of swollen shoot disease. Sahlbergella (see p. 66), a sucking insect, is an important pest.

The West African Cacao Research Institute is situated at Tafo in the Eastern Province, in the midst of one of the badly infected areas. Its information service is available to every cacao farmer who wishes to seek advice.

A soil survey is in progress and new areas are being sought to replace cacao farms in disease-ridden districts. As a result of the findings of the recent Commission of Enquiry into swollen shoot disease, it is recommended that cacao culture should be established in

[18] Anon., *Statistical and Economic Review*, No. 2. United Africa Co., 13 Sept., 1948.

the Eastern Province on a modern basis after the ground has been cleared and left for two to three years before re-planting in larger units.[18a]

Cooperation between the Department of Agriculture and the native farmers has resulted in an improvement in the condition of the cacao, which formerly contained a high proportion of poorly fermented beans. The beans are the cheapest on the market and are known commercially as Accra cacao. They are shipped from Accra, Sekondi and Takoradi.

Nigeria is the third largest cacao producer and accounts for 14% of world supplies. Introductions were made about the same time as in the Gold Coast, but expansion was less rapid. More than 500,000 acres are now in production. As in the Gold Coast, the trees are Forastero-Amelonado. In the Oyo Province, 33% of the trees are over 21 years old, 53% are from 10 to 20 years old and 14% are under 10 years of age.

Nigerian cacao is grown without shade. Cultivation on farms of 2.5 acres is fairly general. Since a compulsory system of grading was introduced, the quality of the beans has improved. Originally four grades were recognised. Now only the first two grades are accepted by the Marketing Board which guarantees a minimum price. The percentage of Grade I cacao was 14.9% in 1946–47 and rose to 80% in 1948–49.[19]

Although black pod, swollen shoot and *Sahlbergella* attacks are fairly widespread, losses by disease have not been so severe as in the Gold Coast. The Marketing Board has financed measures to combat swollen shoot disease.

The Ibadan district gives its name to the local cacao. Nigerian cacao is shipped from the port of Lagos.

Formerly a German colony, the Cameroons (32) are administered under British and French mandates. The French Cameroons ranks fifth in importance as a cacao producing country. Most of the crop, which consists of Forastero cacao, is grown by peasant farmers. Artificial drying is necessitated by the heavy rainfall. Swollen shoot disease is unknown there and other diseases are less prevalent than in the neighbouring countries.

[18a] *Report of the Commission of Enquiry into Swollen Shoot Disease in the Gold Coast.* Colonial No. 236. Colonial Office, London, 1949.

[19] *Trade and Industry in Nigeria.* Jarrold, Norwich, England (for the Government of Nigeria), 1951.

Black pod is a serious menace in the British Cameroons. At present full cover is not given, owing to ruthless pruning. West[20] has recommended closer planting as a remedy.

Drying methods are somewhat primitive and may be the cause of a "hammy" flavour which is liable to occur in the finished products.

Approximately 8000 acres are devoted to cacao in French Equatorial Africa (33) and are cultivated by natives. French Congo is an unimportant source of cacao.

Cacao is a plantation crop in Belgian Congo (34) where 19,000 acres are under cultivation. About one-third of the trees are not yet in production. The average annual production is 2500 tons and the output could be improved if sufficient labour were available.

Exports from Angola (35) amount to little more than 300 tons annually, and are absorbed by Portugal.

Cacao cultivation in Fernando Po (36), a Spanish possession lying 30 miles from the mainland in the Gulf of Guinea, dates from the 16th century. The crop is mainly Forastero and is grown in coastal districts. The industry is well organised and high yields are obtained. Exports (mainly to Spain) have risen slowly since 1925 and now average over 10,000 tons. A little cacao is grown on the mainland in Spanish Guinea.

The first cacao to be planted in Africa was introduced into the islands of Principe (37) and St. Thomé (38) in the Gulf of Guinea about 200 years ago, but did not become an important crop there until the early years of the present century. Forastero cacao is grown in well-managed plantations and 36,000 tons of beans were produced in the year 1910. There has since been a steady decline, largely due to thrips attack (see p. 69) and the present output has dwindled to less than 10,000 tons annually.

On the east side of Africa, cultivation on a small scale has been attempted in Uganda (39), Madagascar (40), Comoro (41), Seychelles (42), Mauritius (43) and Réunion (44). In Madagascar, where 2000 acres are cultivated, the yield is 400 lb. of dry cacao per acre. Exports rose slowly to 400 tons in 1936. Only an insignificant quantity of beans in now exported and the remainder of the cacao is processed in the island and exported in the form of chocolate.

[20] J. West in *Cocoa Conference 1948*. The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1948.

E. ASIA AND THE PACIFIC

Cacao plantations are distributed over a number of islands in the Indian and Pacific Oceans. Although outputs are, as a rule, on a small scale, they contribute appreciably to the world's supplies of Criollo types of cacao.

In the island of Ceylon (45), the climate and soil to the north and east of Kandy are favourable for cacao, which has been grown there for over 100 years. A reputation was established for the delicately flavoured "Old Red Ceylon" Criollo cacao which commands a high price. Some Forastero cacao is now grown. In 1946, there were 19,700 acres of cacao land, consisting of estates and smaller holdings. Estates cacao is marketed by agents at Colombo.

The main crop is harvested between November and January and the light crop season is from May to July. Between the years 1900 and 1910, exports rose from 2000 to 4000 tons. During pre-war years, exports averaged 3000 to 4000 tons and recently declined to less than 3000 tons. Production is now on the upgrade.

In Indonesia, which includes the former Dutch colonies Java (46) and Sumatra (47), the cacao plantations were neglected during the Japanese occupation. Plans for their rehabilitation are now being put into operation and some areas have been re-planted. The dominating types in Java are high grades of Criollo. Pre-war exports (1000–2000 tons annually) went mainly to Holland. Only 500 tons of cacao were exported in 1948.[21]

Small quantities of cacao are produced in Timor (48), New Hebrides (50), New Guinea (51), New Caledonia (52), Fiji (53) and the Philippine Islands (54). New Guinea cacao was introduced from Ceylon and Java by way of Samoa (49). In 1913, Criollo cacao, which suffered from pests, was replaced by Forastero stands. Cacao has been grown in Samoa for many years. In 1940, more than 1500 farms were engaged in cultivation. Cacao grown in Western Samoa (now under mandate to New Zealand) is classified as a high grade. The annual yield averages 2000 tons. Half of the crop is sun dried and the rest is air dried.[22]

[21] *Commodity Reports. Cocoa.* The Food and Agriculture Organization of the United Nations, Washington, D. C., 26 June, 1950.
[22] *Cacao Information Bull., 1,* No. 22, 5 (1949).

F. POTENTIALITIES FOR PRODUCTION IN MALAYA, SARAWAK AND NORTH BORNEO

In 1948, Cheesman[23] investigated the potentialities for developing cacao cultivation in Malaya, Sarawak and North Borneo. The following summary of his report to the British Colonial Office indicates that the prospects for large-scale production in the near future are not very promising.

Rainfall in Malaya is above 80 inches and in some cases exceeds 100 inches annually. Soil erosion is likely to occur, as the country is mountainous. There are some tracts of alluvial soils but their texture is too heavy and drainage is inadequate. Prospects seem more hopeful on volcanic soils. These occur in patches and total 100 sq. miles. Coarser granites are ruled out, through soils being too sandy and lacking in nutrients. The finer granites, while being more suited to cacao, are distributed only in patches. Potential production over the entire peninsula would not amount to more than 100,000 tons annually. At present, Malaya relies almost entirely on its rubber production. Monoculture is always attended by risks of failure or overproduction, therefore the introduction of a new crop, such as cacao, at the expense of some of the rubber would be preferable to planting it on inferior soils liable to become exhausted.

Prospects in Sarawak are comparatively poor and the most optimistic estimate is a production of 10,000 tons.

North Borneo lacks both labour and communication. On the east coast, a rich Andesite soil has not yet been fully exploited and should prove satisfactory for cacao. Climate and rainfall are favourable.

When sufficient planting material is available, trials will be undertaken to find which varieties give the best response. Of the few cacao trees already growing in Malaya and Borneo, at least half are Criollo and the remainder Trinitario types. It is not anticipated that production will be on an appreciable scale before 1960.

2. World Production and Exports of Cacao Beans

An important feature of the *Gordian*, issued at two-monthly intervals in Hamburg, is the statistical section, wherein figures for the

[23] E. E. Cheesman, *Report on Potentialities for the Cultivation of Cocoa in Malaya, Sarawak and North Borneo.* Colonial No. 230. His Majesty's Stationery Office, London, 1948.

TABLE XLVII. World Exports of Cacao Beans from Producing Countries 1895–1935 (in metric tons)[a]

Countries of Production	1895	1900	1905	1910	1915	1920	1925	1930	1935
Gold Coast	13	545	5,620	22,989	78,514	126,596	216,684	189,764	265,227
Nigeria	21	205	478	2,978	9,260	17,429	41,725	53,168	89,552
Ivory Coast	—	—	2	8	114	1,036	6,278	22,239	43,565
Cameroons	120	261	1.414	3,431	3,400	4,112	7,857	10,213	23,374
Fernando Po	500	900	1,863	2,445	3,866	4,741	5,965	11,606	12,000
San Thomé	7,023	13,935	25,669	37,810	29,617	20,023	20,861	9,646	10,884
Togoland	—	—	13	137	475	2,627	4,607	6,166	10,680
Belgian Congo	—	—	193	902	620	355	779	1,195	1,260
Madagascar	—	4	21	54	115	99	157	181	200
Others	100	100	100	200	200	300	942	861	1,030
Africa total	7,777	15,950	35,375	70,954	126,163	177,318	305,855	305,039	457,772
Brazil	10,846	16,916	21,090	29,158	44,980	56,664	64,526	66,862	111,826
Dominican Republic	1,660	5,963	12,604	16,623	20,223	23,390	23,482	20,701	28,271
Ecuador	18,956	18,803	21,128	36,305	37,015	46,773	32,895	19,989	20,000
Venezuela	7,712	11,900	12,701	17,360	18,281	17,598	22,942	16,107	15,000
Trinidad	13,550	14,525	22,018	26,240	24,518	28,466	22,442	24,415	20,134
Grenada	4,350	4,975	5,797	6,031	5,076	6,261	3,719	4,311	4,089
Panama	—	—	20	12	55	474	2,028	4,064	4,749
Costa Rica	—	50	150	184	579	2,154	4,144	7,318	3,749
Jamaica	875	1,200	1,358	1,743	3,479	2,562	2,882	3,052	1,731
Haiti	1,250	2,112	2,462	2,076	2,100	2,226	2,016	1,621	1,629
Cuba	1,345	1,671	1,768	1,412	2,176	11	—	833	10
St. Lucia	369	659	859	743	939	455	530	363	300
Martinique	400	732	470	571	506	474	453	604	200
Guadeloupe	336	294	638	779	927	597	653	104	150
Dominica	300	400	589	573	549	281	356	186	150
Surinam	4,456	2,927	1,682	2,043	1,709	1,794	818	186	64
Others	100	200	800	600	300	400	270	376	205
America total	66,505	83,327	106,134	142,453	163,412	190,580	184,156	171,092	212,757
Ceylon	1,691	1,890	3,225	3,570	3,986	2,819	3,490	3,890	3,517
Netherlands East Indies	960	1,342	1,030	2,479	1,459	1,201	1,201	1,463	1,500
Samoa	—	2	27	505	893	789	675	1,023	800
Others	—	100	100	200	450	1,035	1,644	4,088	2,295
Asia and Pacific total	2,651	3,334	4,382	6,754	6,788	5,853	7,010	10,464	8,112
Total	76,933	102,611	145,891	220,161	296,363	373,751	497,021	486,595	678,641

[a] Anon., *Cardiga Essays on Cocoa*, Max Bicak, Hamburg, 1936.

production and trade of cacao beans are given in detail. Two monthly periodicals, the *International Chocolate Review,* published in Zurich, and *Cacao,* the information bulletin of the American Cacao Center at Turrialba also present statistics on cacao. Detailed information on the international trade of the crop is to be found in a compilation by Montgomery and Taylor[23a] and records of the South American cacao industry, from the early days of the trade to the present time, are assembled in a single volume by Erneholm.[23b]

The expansion of the cacao industry and production trends in individual countries between the years 1895 and 1935 are illustrated by the annual exports cited in Table XLVII.[24] During this period, the Brazilian output increased tenfold and production in the Gold Coast, which was insignificant at the outset, expanded at a rate unparalleled elsewhere. While production was mounting in Nigeria, the Ivory Coast, the Cameroons and the Dominican Republic, yields were declining in many of the older producing ccuntries. Competitive prices for filler grades of cacao succeeded in reducing the demands for superior grades and led either to their replacement by more lucrative crops or to neglect of the plantations which frequently resulted in abandoning them altogether. Between the wars, production even of the baser grades was in excess of consumer demands and the eventual lowering of the market price left the peasant farmers of West Africa without a margin of profit to encourage the replacement of older trees. This circumstance, coupled with the fact that early symptoms of swollen shoot disease are not easily recognised in older trees until after the surrounding trees have become infected, contributed to the decline in output during the succeeding years, when the disease raged unchecked particularly in the Eastern province of the Gold Coast, where, hitherto, the greater part of the country's crop was produced.

The change in distribution of the Gold Coast cacao crop between the seasons 1936–37 and 1949–50 is shown in Table XLVIII.[25,26]

Fortunately a prediction that the world output of cacao would continue to show diminishing returns has not been realised. Produc-

[23a] E. G. Montgomery and A. M. Taylor. *World Trade in Cocoa.* U. S. Department of Commerce, Washington, D. C., 1947.

[23b] I. Erneholm, *Cacao Production of South America.* Holmqvists Boktryckeri A. B., Gothenburg, 1948.

[24] *Gordian Essays on Cocoa.* Rieck, Hamburg, 1936.

[25] *The Gold Coast 1950.* Public Relations Department, Accra, Gold Coast, 1950.

[26] *The Gold Coast 1951.* Public Relations Department, Accra, Gold Coast, 1951.

tion has lately been on the upgrade in Western Ashanti (Gold Coast), Southern Bahia (Brazil) and the French Colonial Empire. The replacement of older trees by high-yielding types, application of scientific methods of control, improvements in transport, more favourable prices and the ideal weather conditions during the seasons 1948–49 and 1949–50 all contributed in arresting the decline of the cacao industry. Adverse weather reduced the output for 1951–52.

TABLE XLVIII. PRE-WAR AND POST-WAR DISTRIBUTION OF CACAO CROPS IN THE GOLD COAST[a,b]

	1936–37	1948–49	1949–50
Eastern Province, %	43	24	22
Remainder of Colony (including Togoland), %	27	31	31
Ashanti, %	30	45	47

[a] *The Gold Coast 1950.* Public Relations Dept., Accra, Gold Coast.
[b] *The Gold Coast 1951.* Public Relations Dept., Accra, Gold Coast.

Where records are available, recent annual returns for the total cacao crops of producing countries are shown in Table XLIX.[27-32] When the total outputs are compared with the annual tonnage of exports from the countries listed in Table L[33-36] it should not be presumed that the differences invariably represent domestic consumption in the producing countries. Stocks are sometimes allowed to accumulate and released during the succeeding years.

During wartime, the system of trading cacao in West Africa underwent a change by the establishment of marketing boards for grading and price-fixing.

Before the war, New York, London, Amsterdam and Hamburg

[27] A. Balleyguier in *Cocoa Conference 1949.* The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1949.
[28] Anon., *Internat. Chocolate Rev., 5,* 26 (1950).
[29] *Commerce in Nigeria, 1,* No. 2, 28 (1950).
[30] *The Gold Coast 1950.* Public Relations Department, Accra, Gold Coast, 1950.
[31] *The Gold Coast 1951.* Public Relations Department, Accra, Gold Coast, 1951.
[32] *Commodity Reports. Cocoa.* The Food and Agriculture Organization of the United Nations, Washington, D. C., 26 June, 1950.
[33] E. G. Montgomery and A. M. Taylor, *World Trade in Cocoa.* U. S. Department of Commerce, Washington, D. C., 1947.
[34] *Internat. Chocolate Rev., 5,* 26 (1950).
[35] *Commodity Reports. Cocoa.* The Food and Agriculture Organization of the United Nations, Washington, D. C., 26 June, 1950.
[36] *Trade and Industry in Nigeria.* Jarrold, Norwich, England (for the Government of Nigeria), 1951.

TABLE XLIX. Annual Production of Raw Cacao 1934/35–1949/50 (in thousand metric tons)[a–f]

	Average 1934/35–1938/39	1946/47	1947/48	1948/49	1949/50
Africa					
Gold Coast	265.1	179.0	210.0	278.0	247.8
Nigeria	89.6	113.0	91.0	104.0	101.3
Ivory Coast	49.9	26.0	35.0	52.3	50.8
French Cameroons	26.0	29.9	46.7	42.0	40.8
French Togoland	8.6	2.8	2.8	1.5	3.3
British Togoland	17.5	16.5	Now included in Gold Coast returns		
Sierra Leone	0.3	0.3	1.4	—	—
St. Thomé	10.5	9.2	8.3	7.4	7.7
Spanish Guinea (including Fernando Po)	11.7	13.2	16.0	14.0	—
Belgian Congo	1.3	1.1	1.5	2.2	1.8
Madagascar	0.3	0.3	—	—	—
North, Central and South America and West Indies					
Brazil	129.9	140.2	110.4	126.5	136.2
Dominican Republic	28.7	30.5	28.4	19.0	27.5
Ecuador	19.2	18.3	16.1	19.5	19.9
Venezuela	16.8	17.4	18.1	18.4	18.6
Colombia	10.5	11.5	8.3	10.0	11.4
Trinidad and Tobago	14.3	5.4	4.1	5.6	6.8
Grenada	3.7	2.8	2.2	2.1	2.4
Jamaica	2.2	2.0	1.7	2.0	2.5
Dominica	0.1	0.1	0.2	—	—
St. Lucia	0.3	—	—	—	—
Costa Rica	6.8	4.9	4.8	6.0	6.3
Cuba	3.2	2.5	3.2	3.2	3.2
Martinique	0.2	0.2	0.2	—	—
Haiti	1.5	1.3	2.0	—	2.1
Mexico	1.1	2.7	3.8	7.0	7.7
Nicaragua	0.4	—	0.5	—	—
Panama	4.8	2.5	3.0	3.0	3.0
Asia and Oceania					
Ceylon	3.6	2.4	2.0	2.4	2.0
Indonesia	1.6	0.4	0.4	0.6	0.8
Philippines	8.0	0.4	0.7	—	—
New Hebrides	1.8	1.4	1.4	1.4	0.7
Western Samoa	1.1	2.7	2.3	2.5	2.5
Total for countries listed	740.6	641.9	626.5	730.6	707.1

[a] A. Balleyguyier, *Cocoa Conference 1949*. The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1949.
[b] Anon., *Internat. Chocolate Review, 5*, 26 (1950).
[c] *Commerce in Nigeria. 1*, No. 2, 28 (1950).
[d] *The Gold Coast 1950*. Public Relations Dept., Accra, Gold Coast.
[e] *The Gold Coast 1951*. Public Relations Dept., Accra, Gold Coast.
[f] *Commodity Reports. Cocoa*. Food and Agriculture Organization of the United Nations, Washington, D. C., 26 June, 1950.

TABLE L. World Exports of Cacao Beans from Producing Countries 1934–49 (in thousand metric tons)[a]

	Average 1934–38	Average 1939–43	1944	1945	1946	1947	1948	1949
Africa								
Gold Coast	266.2	210.2	192.8	219.7	236.0	169.0	196.4	252.0
Nigeria	90.8	96.6	71.1	78.2	100.0	111.0	91.0	104.0
Ivory Coast	47.1	34.6	31.5	33.1	25.8	34.6	49.4	51.1
French Cameroons	24.8	24.0	43.2	35.9	38.8	47.4	42.5	40.9
French Togoland	8.6	4.3	2.8	1.8	2.7	2.9	1.5	3.2
Sierra Leone	0.3	0.5	1.5	0.4	—	—	1.4	—
St. Thomé	10.3	6.4	12.2	9.1	—	9.9	8.0	—
Spanish Guinea (including Fernando Po)	10.4	10.9	—	—	—	—	13.0	14.8
Belgian Congo	1.3	1.2	—	—	—	1.4	1.5	1.8
Central and South America and West Indies								
Brazil	113.6	111.7	101.9	83.4	130.5	99.0	72.7	132.2
Dominican Republic	23.5	23.2	25.6	18.8	26.2	30.0	19.4	23.4
Ecuador	20.0	14.6	13.7	16.8	16.5	20.3	16.7[c]	18.9[c]
Venezuela	16.5	14.1	16.1	12.4	16.1	11.9	17.9	13.5
Trinidad and Tobago	15.0	7.3	4.8	4.6	3.0	4.1	8.2	4.4
Grenada	3.9	3.1	3.1	2.9	2.7	2.4	2.9	—
Jamaica	2.1	2.0	—	—	—	1.9	1.4	—
Costa Rica	5.5	5.5	4.2	1.3	—	—	4.3	6.6
Haiti	1.5	1.5	1.5	1.3	—	—	—	—
Panama	4.6	3.5	1.6	0.4	—	—	3.8	3.2
Asia								
Ceylon	3.7	3.2	2.3	—	—	1.2	2.4	2.8
Indonesia	1.6	—	—	—	—	—	1.2	2.2
Oceania								
New Hebrides	1.7	1.3	—	—	—	—	1.3	1.5
Western Samoa	1.1	—	—	—	—	—	2.2	2.3
Total for countries listed	674	580	[b]	[b]	[b]	[b]	560	680

[a] E. G. Montgomery and A. M. Taylor, *World Trade in Cocoa*. U. S. Department of Commerce, Washington D. C., 1947. *International Chocolate Review, 5*, 26 (1950). *Commodity Reports. Cocoa.* Food and Agriculture Organization of the United Nations, Washington D. C., 26 June, 1950. *Trade and Industry in Nigeria*, Jarrold, Norwich, England 1951.

[b] Totals for 1944–47 not given because figures were not available for several countries.

[c] From Guayaquil only.

were the chief markets for the sale of cacao to consumer countries. At the close of the war, the Food and Agriculture Organization of the United Nations took a hand in distribution of stocks. Allocations through this Organization have now been discontinued. The Amsterdam market was reopened in 1949. Wartime and post-war distribution in Great Britain was controlled by the Ministry of Food until the London market was re-opened. By far the greatest volume of the trade is conducted through the New York Cocoa Exchange. The present movement of cacao stocks is influenced to some extent by currency restrictions. Whereas the main supplies to Britain, France, Belgium and Spain are derived from their colonial territories, countries in Eastern Europe are importing less cacao now than pre-war, owing to the control of foreign exchange. Lack of hard currency has likewise restricted the volume of European trade with Ecuador and Venezuela. Furthermore, the destination of a high proportion of the British West African cacao crop to hard currency areas has impeded the recovery of the industry in some countries which are at present unable to obtain sufficient raw material for the expansion of their trade in manufactured goods.

3. Imports of Cacao Beans into Consuming Countries

Towards the close of the nineteenth century, France was the chief purchaser of cacao. About fifty years ago, the United States became the leading consumer country and by 1920 was importing 40% of the world output of cacao. At that time, Germany ranked second, the United Kingdom third, Holland fourth and France fifth in importance as consumer countries. While the United States maintained its lead, the United Kingdom and Germany competed for second place in the period between the wars. The pattern of distribution of cacao purchases between the years 1895 and 1935 is shown by the tonnage of annual imports into the consumer countries listed in Table LI.[37] The figures represent total imports. Re-exports of cacao beans and exports of manufactured products have not been taken into account. The volume of annual imports during the immediate pre-war and post-war years can be compared by referring to Table LII.[38,39] The percentage distribution of total world imports to consuming countries

[37] Anon., *Gordian Essays on Cocoa.* Rieck, Hamburg, 1936.
[38] *Internat. Chocolate Rev., 5,* 26 (1950).
[39] *Commodity Reports. Cocoa.* The Food and Agriculture Organization of the United Nations, Washington, D. C., 26 June, 1950.

TABLE LI. World Imports of Cacao Beans with Consuming Countries 1895–1935 (in thousand metric tons)[a]

	1895	1900	1905	1910	1915	1920	1925	1930	1935
North and South America	13.8	19.8	36.8	53.6	89.2	153.7	183.6	185.9	292.9
U. S. A.	13.2	18.8	35.2	50.3	85.1	142.8	165.6	165.1	271.3
Canada	0.2	0.4	0.7	1.5	2.5	6.5	7.2	8.7	12.2
Argentine	0.4	0.6	0.7	1.0	1.2	2.9	3.9	4.8	4.7
Chile	—	—	—	0.1	0.1	0.2	0.4	0.6	0.7
Others	-	—	—	0.7	0.3	1.3	6.5	6.7	4.0
Europe	59.2	81.3	105.3	148.1	220.6	213.2	292.6	290.2	362.2
Austria	} 1.1	1.5	2.9	5.4	4.0	4.3	} 4.8	6.0	6.2
Czechoslovakia							7.7	7.6	13.4
Hungary							2.0	2.3	5.0
Belgium	1.7	2.1	3.0	4.8	4.8	6.2	7.0	7.1	9.3
Denmark	0.6	0.7	1.1	1.6	4.7	2.9	2.1	3.0	4.6
France	15.2	17.5	21.7	25.1	35.3	45.3	43.6	37.3	43.4
Finland	0.04	0.07	0.06	0.1	0.2	0.1	0.1	0.1	0.2
Germany	10.0	19.2	29.6	43.9	43.1	45.0	79.7	75.6	74.8
Great Britain	11.0	16.9	20.2	24.1	47.3	51.5	57.2	57.9	83.7
Italy	0.6	0.6	1.0	1.9	6.5	4.7	8.0	7.3	12.0
Jugoslavia	0.01	0.01	0.01	0.02	—	—	0.4	0.7	1.1
Netherlands	8.6	11.8	10.7	19.2	40.1	25.4	47.6	51.0	62.0
Norway	0.15	0.4	0.5	0.9	1.8	3.4	2.1	2.1	3.0
Poland	—	—	—	—	—	1.0	3.7	5.6	6.6
Portugal	0.1	0.1	0.1	0.2	0.15	0.1	0.3	0.3	0.5
Roumania	0.02	0.03	0.06	0.2	0.3	0.3	0.8	1.6	2.5
Spain	6.5	4.7	6.1	5.5	6.7	8.5	9.6	8.2	10.4
Sweden	0.4	0.5	0.9	1.2	2.6	3.5	3.7	3.7	5.7
Switzerland	2.2	3.6	5.2	9.1	17.2	10.4	6.9	7.1	7.7
U.S.S.R.	1.0	1.5	2.2	3.7	5.7	—	3.6	2.7	4.7
Others	—	—	—	0.1	0.2	0.7	1.7	3.0	5.4
Africa, Asia, Oceania	0.5	1.3	1.2	2.7	3.3	9.1	7.4	7.2	11.8
South Africa	—	—	—	0.03	0.05	0.2	0.04	0.3	0.5
Philippines	0.2	0.5	0.6	0.8	0.7	3.2	1.8	1.4	1.5
Australia and New Zealand	0.3	0.8	0.6	1.3	2.2	5.0	4.9	4.7	8.7
Others	—	—	—	0.6	0.3	0.7	0.7	0.8	1.1
Total	73.5	102.4	143.3	204.4	313.1	376.0	483.6	483.3	666.9

[a] Anon., *Gordian Essays on Cocoa*. Rieck, Hamburg, 1936.

TABLE LII. Annual Imports of Cacao Beans into Consuming Countries, 1934–38 and 1947–49 (in thousand metric tons)[a,b]

	1934–38 (average)	1947	1948	1949
Americas				
U. S. A.	249.6	267.0	247.7	285.2
Canada	11.6	15.0	17.8	18.4
Mexico	0.8	—	—	—
Argentina	4.9	5.0	4.6	—
Chile	0.8	—	0.7	1.1
Colombia	3.0	4.0	4.5[c]	4.0[c]
Europe				
Austria	6.4	—	0.7	—
Benelux	9.9	13.7	13.9	10.8
Czechoslovakia	11.3	7.7	8.8	—
Denmark	4.3	3.2	2.5	4.4
France	43.0	48.0	51.4	66.0
Germany	81.2	—	—	18.3[d]
Gt. Britain	104.0	109.0	109.7	149.2
Hungary	3.9	0.2	0.6	—
Ireland	1.6	—	3.5	3.5
Italy	9.1	7.5	4.6	8.6[c]
Netherlands	64.7	40.0	21.8	39.4
Norway	3.1	3.5	3.3	4.1
Poland	7.1	1.5	1.9	—
Portugal	0.5	—	0.6	0.7
Spain	10.9	8.0	12.1	10.1 (Jan.–Nov.)
Sweden	5.7	7.8	8.8	10.1
Switzerland	7.7	9.3	11.0	8.5
U.S.S.R.	7.8	6.0	10.0	—
Africa, Asia, Oceania				
Egypt	0.3	—	0.8	0.3 (Jan.–Sept.)
Union of South Africa	1.2	4.5	5.5	3.1
Japan	1.6	1.1	1.2	—
Palestine (Israel)	0.3	—	—	—
Australia	6.5	15.0	12.0	8.0
New Zealand	1.6	—	2.3	—
Total	664.4	577.4	562.3	653.8

[a] *Internat. Choc. Review*, 5, 26 (1950).
[b] *Commodity Reports. Cocoa.* Food and Agriculture Organization of the United Nations, Washington D. C., 1950.
[c] Estimated.
[d] Western Germany only.

is shown for a similar period in Table LIII,[40] wherein the most striking change to be noted is the shrinkage in volume of the German cacao industry owing to the war. Recent production there represents a

TABLE LIII. Percentage Uptake of Total World Cacao Imports by Consuming Countries[a]

	1934/38 (average)	Actual crop 1947/49	Estimates for crop years 1948/49	1950/52
Americas				
U. S. A.	37.2	44.2	37.8	39.6
Canada	1.8	3.2	2.5	2.5
Central and South America	1.6	2.2	1.8	1.5
Europe				
United Kingdom	15.0	18.0	19.4	18.2
Germany	12.4	0.8	3.7	4.6
Netherlands	9.5	5.4	5.7	6.1
France	6.6	8.7	9.1	9.2
Others, including U.S.S.R.	13.8	13.5	15.9	15.2
Rest of world	2.1	4.0	4.1	3.1

[a] C. H. Woodhouse, *Cocoa Conference 1949*, p. 103. The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1949.

TABLE LIV. Crop Sales, Gold Coast, Brazil and Nigeria, 1948 and 1949[a, b, c]

	Gold Coast		Brazil		Nigeria	
	1948, %	Jan.–Sept. 1949, %	1948, %	1949, %	1948, %	Jan.–Sept. 1949, %
U. S. A.	32.8	38.5	75.0	78.7	39.0	40.8
Canada	4.0	3.6	0.5	0.3	4.8	3.0
Central and S. America	—	0.1	8.2	4.8	—	—
Great Britain	29.3	24.2	3.6	4.0	46.4	52.4
Netherlands	5.8	9.7	3.0	5.4	9.1	2.5
Western Germany	5.0	8.5	—	—	—	—
U.S.S.R.	3.8	2.2	—	—	—	—
Belgium	1.5	0.7	2.9	2.2	—	0.1
Other Europe	10.2	8.3	6.2	4.4	0.3	1.2
Asia, Africa and Oceania	7.6	4.2	0.6	0.2	0.4	—

[a] *The Gold Coast 1950.* Public Relations Dept., Accra, Gold Coast.
[b] *The Gold Coast 1951.* Public Relations Dept., Accra, Gold Coast.
[c] *Commodity Reports. Cocoa.* Food and Agriculture Organization of the United Nations, Washington D. C., 1950.

[40] C. H. Woodhouse in *Cocoa Conference 1949*. The Cocoa, Chocolate and Confectionery Alliance Ltd., London, 1949.

recovery of about one-third of pre-war trade. British and French imports have already surpassed their pre-war levels and the trade is gradually being re-established in the Netherlands which has now resumed its role as an exporter of cacao products. The tonnage of British exports of cacao products is now well ahead of the pre-war volume of trade.

Imports of cacao into the United States have remained at practically pre-war level, despite the increase in population. This is partly

TABLE LV. IMPORTS OF CACAO INTO NORTH AMERICA (in thousand metric tons)[a]

Origin of import	1935/39 (average)	1948	1949	1950
Africa				
French Colonial Empire	16.5	10.0	5.6	3.1
Gold Coast	72.8	82.4	87.5	94.0
Nigeria	36.6	27.7	45.1	49.1
Spanish Colonies	Negligible	2.3	—	6.4
Other countries	2.3	2.6	0.6	3.0
Central America				
Mexico	Negligible	0.2	Negligible	3.4
Dominican Republic	22.1	23.4	20.3	24.8
Trinidad and Tobago	8.0	4.4	3.2	3.5
Other countries	7.5	8.4	7.8	6.7
South America				
Brazil	85.6	61.1	90.7	73.5
Ecuador	5.7	10.4	11.9	17.4
Venezuela	5.8	13.2	10.5	12.0
Other countries	0.3	—	—	—
Asia and Oceania	0.3	0.7	1.7	0.7
Europe (re-exports)	4.9	0.4	—	1.0
Total	*269*	*247*	*285*	*299*

[a] *Internat. Choc. Review, 6,* 180 (1951).

due to the competition of cheaper lines of confectionery, such as peanuts and chewing gum. Moreover the advanced price of cacao has caused manufacturers to economise on chocolate by spreading it more thinly on coated goods.

Crop sales to consuming countries in 1948 and 1949 are presented in Table LIV[41 43] as percentages of the total exports from the

[41] *The Gold Coast 1950.* Public Relations Department, Accra, Gold Coast, 1950.
[42] *The Gold Coast 1951.* Public Relations Department, Accra, Gold Coast, 1951.
[43] *Commodity Reports. Cocoa.* The Food and Agriculture Organization of the United Nations, Washington, D. C., 26 June, 1950.

three most important producing countries. The annual imports of cacao beans (in thousand metric tons) into North America from pre-war and post-war sources are listed in Table LV.[44]

A chocolate industry is gradually being built up in Israel, where the influx of immigrants from Europe in the 1930's created a demand which was responsible for the establishment of eight factories. During the war, production was maintained by means of raw materials obtained from military authorities for the purpose of supplying chocolate to the allied armies in the Middle East. The factories were modernised between 1945 and 1950 to meet the consumer needs of the ever-increasing immigrant population. Manufacture is likewise developing on an increasing scale in British Dominions. Imports of additional supplies of beans into cacao-producing countries where chocolate industries are expanding have been noted earlier in this chapter (see p. 254).

4. Annual Consumption of Cacao per Head of the Population in Principal Consuming Countries

Trends in per capita consumption of cacao in U. S. A., Britain, Germany, France and the Netherlands between 1895 and 1935 are shown in Table LVI.[45] In the period under consideration, consumer demands in the Netherlands, where cocoa powder was invented, were consistently heavier than elsewhere. Although Britain was the pioneer of the chocolate confectionery trade, the annual consumption of cacao per head there was comparable with that of France and Germany in 1910. By 1915, when considerable supplies of beans were available from British West Africa, the annual intake of cacao by the British populace had doubled. Although well below the Dutch level, American demands outstripped those of Britain between the years 1910 and 1915. In 1935, the American citizen continued to be the second best customer by consuming twice as much cacao as the French and German subject. The British consumer demand was then about 80% of the individual American uptake. The consumer levels for 1950–51 illustrate how the pattern of distribution has altered since pre-war days.

Figures for civilian consumption in U. S. A., Canada and Britain

[44] *Internat. Chocolate Rev., 6,* 180 (1951).
[45] Anon., *Gordian Essays on Cocoa.* Rieck, Hamburg, 1936.

during wartime are presented in Table LVII.[46] The demand for chocolate confectionery continues at a high level in Britain, where approximately 50% of the sugar confectionary ration was provided by chocolate goods. Post-war Dutch consumption is on a much lower level

TABLE LVI. Annual Consumption of Cacao 1895–1935 and 1950–51 (in pounds per head)[a,b]

	U. S. A.	U.K.	Germany	France	Netherlands
1895	0.44	0.59	0.42	0.88	3.96
1900	0.55	0.90	0.75	0.99	5.08
1905	0.90	1.03	1.08	1.23	4.01
1910	1.21	1.16	1.50	1.39	7.22
1915	1.89	2.24	1.41	1.96	14.09
1920	2.97	2.40	1.65	2.53	8.14
1925	3.12	2.79	2.77	2.40	14.12
1930	2.97	2.77	2.53	1.96	14.17
1935	4.80	3.83	2.46	2.27	15.86
1950–51	3.74	4.88	2.55	3.08	11.92

[a] Anon., *Gordian Essays on Cocoa.* Rieck, Hamburg, 1936.
[b] *Cocoa Situation Report No. 3.* The Food and Agriculture Organization of the United Nations, Rome, 1952.

TABLE LVII. Civilian Consumption of Cacao in U. S. A., Canada and the United Kingdom (in pounds per head per annum)[a]

	U. S. A.	Canada	U.K.
1935/39 (average)	3.5	3.7	3.5
1940	3.9	4.7	5.8
1941	3.8	5.3	5.3
1942	3.1	3.9	4.5
1943	2.6	4.4	4.0
1943/44	3.0	—	3.5

[a] *Food Consumption Levels in U. S. A., Canada and the United Kingdom.* His Majesty's Stationery Office, London, 1944.

than formerly. In the process of rebuilding the cacao industry there, a bid was made to recapture former overseas trade by diverting part of the stocks allocated through the Food and Agriculture Organization to the production of press butter and cocoa powder for export. Although the chocolate industry is again prospering in France, the return to normal pre-war domestic consumption has been hampered by

[46] *Food Consumption Levels in U. S. A., Canada and the United Kingdom.* His Majesty's Stationery Office, London, 1944.

currency depreciation. Per capita consumption of cacao in Western Germany, now back to pre-war level, is partly met by imports of finished products.

5. How Cacao is Utilised in Consuming Countries

The definitions of cacao products and the collection and presentation of output statistics were under discussion at the Lausanne Conference of the Congrès International des Fabricants de Chocolat et de Cacao.[47]

The agreed definitions, which differ in some respects from those laid down by the U. S. Food and Drugs Administration, are summarised below.

Cacao nibs: Residual shell and germ must not exceed 5% and ash 10% of the fat-free dry weight.

Chocolate liquor (cacao mass): Minimum cocoa butter content 50%.

Cocoa powder: Maximum alkalinity of ash equivalent to 100 ml. of normal alkali per 100 g. of fat-free cacao solids. Minimum fat content 18% on dry weight.

Low fat cocoa: Minimum fat content 10% on dry weight.

Sweetened cocoa powder: Minimum cocoa powder content 32%.

Cocoa butter is defined as the fat mechanically extracted from cacao nibs or chocolate liquor.

Chocolate: Minimum fat-free cacao solids 14% and minimum fat-free cacao solids and cocoa butter together 32%.

Milk chocolate: Minimum cocoa butter and fat-free cacao solids together 25%; minimum dried milk content 12.5%, consisting of at least 3% of butter fat and 9.5% of skim milk solids.

In countries where the activities of chocolate undertakings are confined solely to the manufacture of the above-mentioned cacao products, no difficulties are anticipated in the presentation of records. The issue becomes complicated when other confectionery lines, such as chocolate-flavoured sweetmeats, are manufactured side-by-side with chocolate in the same factory. It is then difficult to draw a line of demarcation, for instance, between sweetmeats thinly coated with milk chocolate and chocolate-flavoured fudge or toffee containing cocoa butter as an ingredient. It is doubtful whether either of the latter can appropriately be described as chocolate confectionery. Moreover, several chocolate-making firms in England are also engaged in the bakery industry and produce supplies of chocolate layer cake and

[47] *Compte Rendu, Congrès International des Fabricants de Chocolat et de Cacao, Lausanne 1950.* Office International du Cacao et du Chocolat, Brussels, 1950.

Swiss rolls, etc. for the catering industry and some of them manufacture chocolate-coated ice cream as a sideline. Furthermore, some overlapping may occur when chocolate coating, already accounted for in the records, is sold to firms making covered goods and appears in their returns for chocolate confectionery. On the whole, records will be more reliable if the aim is not too comprehensive. On the other hand, a record of the contribution made by cacao beans to the pharmaceutical industry, in the form of cocoa butter, chocolate-coated pills, theobromine and caffeine would be of interest if it were available.

TABLE LVIII. Output of Cocoa Preparations in France (in thousand metric tons)[a]

	1938	July–Dec. 1945	1946	1947	1948
Chocolate tablets	65.0	21.8	55.6	52.7	59.3
Sweetened cocoa and drinking chocolate	6.5	1.3	2.3	2.9	6.6
Cocoa powder	—	2.0	4.8	3.8	4.3
Cocoa butter	4.0	1.6	3.7	3.1	5.0
Chocolate confectionery	16.0	1.3	3.3	3.1	5.0

[a] *Compte Rendu, Congrès International des Fabricants de Chocolat et de Cacao Lausanne, 1950.* Office International du Cacao et du Chocolat, Brussels, 1950

TABLE LIX. Output of Cocoa Preparations in Denmark (in thousand metric tons)[a]

	1938	1948
Cocoa powder	0.55	0.55
Drinking chocolate	1.61	0.27
Chocolate tablets	3.34	2.98
Chocolate coating	2.65	1.09
Chocolate confectionery	5.47	4.19

[a] *Compte Rendu, Congrès International des Fabricants de Chocolat et de Cacao, Lausanne, 1950.* Office International du Cacao et du Chocolat, Brussels, 1950.

Published returns of the French cocoa industry, shown in Table LVIII[48] give the output of chocolate tablets, sweetened cocoa and drinking chocolate, cocoa butter and chocolate confectionery. In the Danish records (Table LIX)[49] separate figures are given for cocoa powder and drinking chocolate. Official records for production in the United States are more detailed in that different types of coating and

[48] *Compte Rendu, Congrès International des Fabricants de Chocolat et de Cacao, Lausanne 1950.* Office International du Cacao et du Chocolat, Brussels, 1950.
[49] *Ibid.*

chocolate are listed as separate items. The output of 31 factories in 1947 and the estimated output of 39 factories functioning in 1949 are presented in Table LX.[50] The annual exports of cocoa preparations from the United States are shown in Table LXI[51] and those from the Netherlands in Table LXII.[52] Details of British production and home consumption of chocolate confectionery, couverture (coating), cocoa powder and drinking chocolate in 1950 are set out in Table

TABLE LX. Output of Cocoa Preparations in the United States of America (in thousand metric tons)[a]

	1947	1949
Chocolate coating (total)	190.9	154.0
sweet	102.0	102.8
milk	73	33.7
liquor	15.9	17.5
Solid chocolate (except coating)	130.6	91.0
sweet	30.4	18.1
plain milk	61.7	39.6
nut milk	38.5	31.6
unspecified	—	1.7
Cocoa powder	78.4	69.6
consumer size	19.0	27.5
bulk container	45.8	34.0
sweetened or mixed	13.6	8.1
Cocoa butter	11.8	25.9
Chocolate syrups	43.1	Not available

[a] *Census of Manufacturers*, Series MC61T-1, U. S. Department of Commerce, March 1949.

TABLE LXI. United States: Exports of Cocoa Preparations 1947–49 (in thousand metric tons)[a]

	1947	1948	1949
Cocoa butter	0.83	0.68	3.58
Cocoa powder	2.30	2.63	1.56
Chocolate	1.27	0.59	0.48

[a] *Commodity Reports. Cocoa.* Food and Agriculture Organization of the United Nations, 26 June, 1950.

[50] *Census of Manufacturers.* U. S. Department of Commerce. Series MC6IT-1, 7 March, 1949.
[51] *Commodity Reports. Cocoa.* The Food and Agriculture Organization of the United Nations, Washington, D. C., 26 June, 1950.
[52] *Ibid.*

LXIII[53] and the export figures for the years 1947 to 1949 are shown in Table LXIV.[54] In addition to the commodities listed, Britain is now finding overseas markets for cocoa butter, but continues to import small quantities for home consumption. The main British markets for cocoa preparations are Switzerland, the British Empire, the United States, Germany and the Netherlands.

Partly owing to discriminations in the demands of sections of the public and largely governed by the search for favourable markets, there is a small but steady exchange of cocoa preparations between the producing countries.

TABLE LXII. NETHERLANDS: EXPORTS OF COCOA BUTTER AND COCOA POWDER, 1948 AND 1949 (in thousand metric tons)[a]

	1948	1949
Cocoa butter	5.4	6.5
Cocoa powder	4.6	7.0

[a] *Commodity Reports. Cocoa.* The Food and Agriculture Organization of the United Nations, Washington D. C., 26 June, 1950.

TABLE LXIII. GREAT BRITAIN: TOTAL PRODUCTION AND HOME CONSUMPTION OF COCOA PREPARATIONS, 1950 (in thousand metric tons)[a]

	Total production	Home consumption
Chocolate and chocolate confectionery	203.2	179.8
Chocolate couverture (coating)	27.4	24.8
Cocoa powder and drinking chocolate	31.1	15.8

[a] *The Alliance Journal, 3,* No. 2, v (1951).

TABLE LXIV. GREAT BRITAIN: EXPORTS OF COCOA PREPARATIONS 1947–49 (in thousand metric tons)[a]

	1947	1948	1949
Cocoa powder, drinking chocolate and chocolate for further processing	17.8	7.4	14.2
Moulded chocolate, chocolate confectionery, cocoa cake, etc.	12.1	30.2	29.3

[a] *Commodity Reports. Cocoa.* The Food and Agriculture Organisation of the United Nations, Washington, D. C., 26 June, 1950.

[53] *The Alliance Journal, 3,* No. 2, v (1951).
[54] *Commodity Reports. Cocoa.* The Food and Agriculture Organization of the United Nations, Washington, D. C., 26 June, 1950.

6. The Cacao Situation up to 1951–1952

In 1949–50 the world cacao crop attained a record level of 789,800 tons. Production for the season 1950–51 amounted to 777,000 tons and was followed by a sharp decline to 676,000 tons in 1951–52, as a consequence of belated but protracted rains in Africa and drought in Brazil. Forecasts indicate that no major increase above the average yields for the seasons 1948–51 is probable within the next five years.[55,56]

While production was on the upgrade, the entire output was absorbed by consumer demands. The absence of a surplus to tide over the subsequent decline resulted in a considerable increase in the price of cacao, which has brought about some changes in distribution. Net imports have declined slightly in the United States, the United Kingdom, France and the Netherlands. The rehabilitation of the cacao industry and a renewal of industrial prosperity are responsible for the increased uptake in Western Germany which is now the third largest importer of cacao beans, owing to the reduced uptake by France. The United Kingdom is importing twice as much cacao as Western Germany and the uptake in the United States is nearly three times that of the United Kingdom.

[55] *Commodity Reports. Cocoa, No. 2.* Food and Agriculture Organization of the United Nations, Washington, D. C., 1951.

[56] *Cocoa Situation, Report No. 3.* Food and Agriculture Organization of the United Nations, Rome, 1952.

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